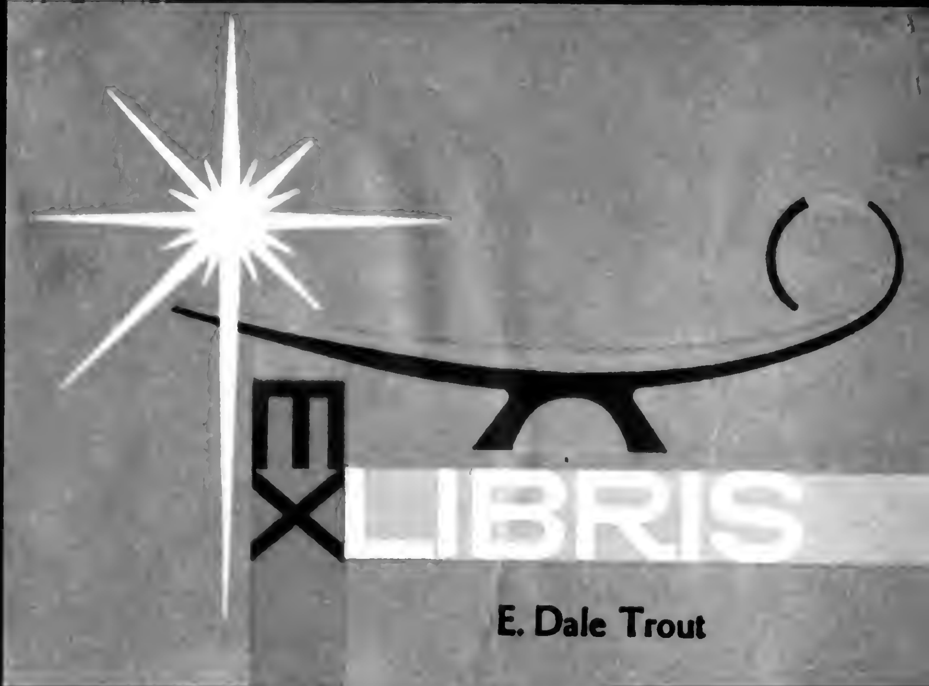
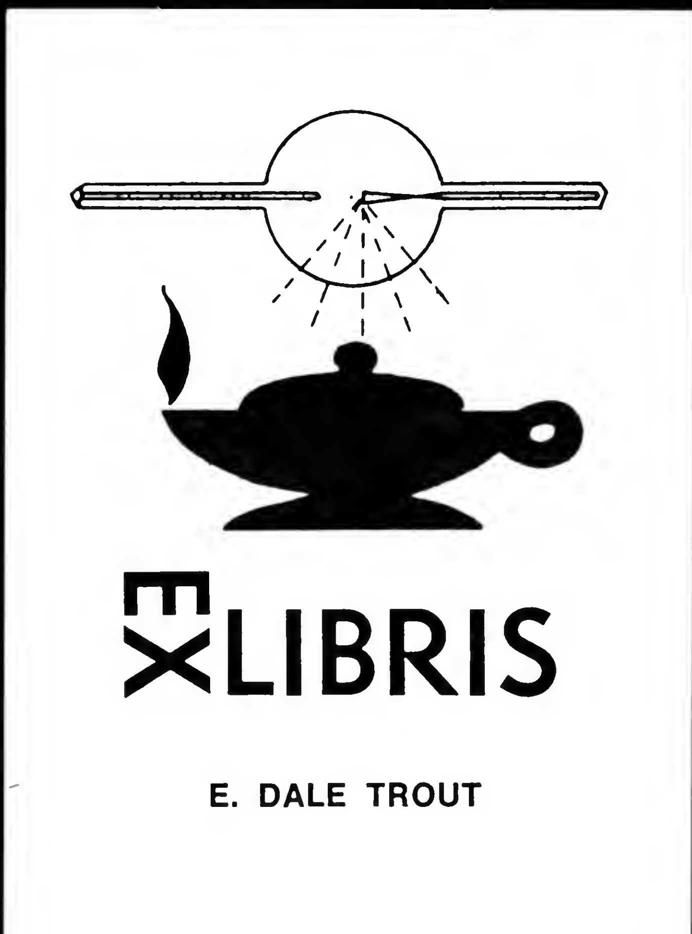
"Model Engineers" Series No. 10

X-Rays

R. P. Howgrave-Graham

London circa 1900


EX LIBRIS
E. Dale Trout


EX LIBRIS
E. DALE TROUT

The "Model Engineer" Series. No. 19

X-RAYS

SIMPLY EXPLAINED

A Handbook on Röntgen Rays in Theory and Practice

BY

R. P. HOWGRAVE-GRAHAM, M.I.E.E.

THIRD EDITION, COMPLETELY REVISED

FULLY ILLUSTRATED
WITH SEVEN FULL-PAGE PLATES

LONDON
PERCIVAL MARSHALL & CO.
66 FARRINGDON STREET, E.C.

CONTENTS

CHAP.		PAGE
I.	Historical and Explanatory . . .	9
II.	Properties, Nature, and Uses of Röntgen Rays	41
III.	Apparatus for the Production of Suitable Discharge	47
IV.	Röntgen Ray Tubes	54
V.	Practical X-Ray Work	72

PREFACE

In preparing the third edition of this handbook I have endeavoured to give a concise account of some of the experiments and discoveries which have led up to the present knowledge of Röntgen rays and their application to pathology. It is intended primarily for students and amateurs, and gives no account of the more complicated and expensive apparatus, nor of the latest developments in hospital methods, but I hope that it may also be of some use to the practical man, as it seems to have been in its earlier form. The original intention was to write a second book in continuation and completion of the first edition, but it has proved more convenient to revise and condense the previous chapters sufficiently to allow the inclusion of the whole in its former small compass. It is hoped that this course will prove equally satisfactory to new readers and existing owners of the first edition, as no matter of any importance contained therein is omitted here and much that is new has been added.

The history and theory of the subject can only be lightly sketched, but I have endeavoured to treat them in such a way as to awaken interest which will carry the reader beyond the mere mechanical production of radiographs as curiosities.

While research and experiment with Röntgen rays have progressed there has been contemporaneous development of the severely practical side in the wards of great hospitals and in the workshops of the firms which supply them with apparatus, but unfortunately even the elementary theory of the subject has sometimes been inadequate.

There are still those who have not learnt the lesson which James Mill impressed upon his son, that there is no antagonism between theory and practice, but that success in the latter must depend on accuracy in the former. The truly practical man feels with his mind as with his fingers, and can not only produce a required result with ease and certainty, but knows the principles involved, and, perceiving the origin of a difficulty, has the patience to surmount it. He is the scientific "clairvoyant"—a word which may be applied here, in spite of its present degraded use, to such pioneers in the world of knowledge as Faraday, Sir W. Crookes, and Sir J. J. Thomson—the clear-seers, whose minds often predicted the results which they or others afterwards obtained experimentally—"Through faith obtained promises, having seen them and greeted them from afar."

EXPLANATIONS OF TERMS USED

Annex.—Annex is the term applied to a subsidiary bulb or tube communicating with the main portion of a Crookes' or X-ray tube. The projections surrounding the electrodes in the various examples, illustrated in Plate I., are all instances of the annex.

Anode.—The anode of any appliance, such as a plating bath, accumulator, or vacuum tube, is the electrode by which the current enters. (*Note*) This statement is made on the usual assumption of direction.

Cathode.—The cathode of any appliance is the electrode by which the current leaves it.

Electrode.—The electrodes of a vacuum tube are pieces of metal of any desired shape placed within the tube and usually attached internally to a small piece of platinum wire which passes out through the glass and is sealed into it. Currents are led to the electrodes by connecting the source of supply to the platinum which projects outside the tube.

Electrostatic Attraction is the attractive force between two oppositely charged bodies.

Electrostatic Repulsion is the repulsion between two similarly charged bodies.

Electromotive Force or E.M.F.—An electromotive force is a force tending to move or drive electricity through a resistance or against an

opposing E.M.F. The unit for its measurement is the volt. The application of the term is generally limited to the force tending to drive an electric current round a conducting circuit.

Fluorescence.—Fluorescence is the direct conversion into light of some other form of energy, usually electric or electromagnetic, imparted to a body from outside, and always ceases with the exciting cause.

Mean Free Path.—The mean free path of a gaseous molecule is the average distance to which it can move without coming into collision with other molecules.

Molecule.—The word molecule literally signifies a *little mass*, and, as used in this book, must have no further meaning attached to it. The ultimate state of division of the rapidly moving stream which constitutes *radiant matter* can only be touched upon here, and the terms *particle* and *molecule* must both be interpreted only in their widest sense.

Phosphorescence.—This term as applied to vacuum-tube phenomena is used for the emission of light by certain substances after the excitation of fluorescence has ceased; thus the glass of a Röntgen-ray bulb sometimes continues to glow after the cessation of the discharge.

Radiability.—This is a term suggested by Mr Hyndman for the degree of penetrability or transparency of a substance to any given kind of radiation.

X-RAYS SIMPLY EXPLAINED

CHAPTER I

HISTORICAL AND EXPLANATORY

Preliminary.—The interesting phenomena resulting from the discharge of electricity at high electromotive force through gases at pressures ranging from two or three atmospheres to about $\frac{1}{200000000}$ of an atmosphere will be discussed in historical order up to the discovery of the X-rays by Professor Röntgen.

A suitable glass bulb for studying the effects of discharges at comparatively low vacua may contain two electrodes provided with knobs attached to brass rods capable of sliding in a tightly fitting packed neck so that adjustment of the discharge-distance is possible. The base of the bulb can be screwed to an air-pump and exhaustion carried to any desired degree.

Discharge—Phenomena.—The discharge from an ordinary induction coil between the electrodes at atmospheric pressure takes well-known forms.

With the electrodes too far separated for any actual spark to pass, thin purple tree-like streaks proceed from them and appear to bush out in all directions, while from the tips of the smallest twigs, as one may term them, straight and very fine blue lines seem to stick out like the hairs of a brush; this appearance originated the term "brush discharge." The effect is far more noticeable if the discharge takes place between points or is the result of a rapidly oscillating E.M.F. When the distance between the electrodes is nearly reduced to the maximum length of spark obtainable from the coil, the discharge becomes a long purple thread with abortive tree-like branches leaving it at different points along its track; these subdivide into finer and finer streaks until they are lost to sight and reach their destination as silent discharges. At a still shorter distance the spark is wavy and free from ramifications. Its colour is bright blue and it is accompanied by a loud snap. With further approximation of the electrodes the spark assumes a reddish colour and thickens, the noise being greatly reduced; at the same time the heating effect is much intensified and reaches a maximum when the electrodes are nearly in contact. In these circumstances the spark appears as a thin blue streak surrounded by a thick yellow, slightly luminous sheath of hot gas. If the spark-frequency is increased the time-interval for the cooling of the gap between the discharges is so far reduced as to maintain the gases in a state of high temperature and

low resistance. If the electrodes are placed in line and are free in space instead of being enclosed in a bulb the phenomenon known as an arc then replaces that known as a spark; the thin blue line almost vanishes, but an enlarged form of the yellow sheath is carried upward in an arch or peak somewhat resembling the low-voltage carbon *arc*, so named by Sir Humphry Davy because of its appearance. A long and thick arc of this type is a danger-signal, inasmuch as it indicates the presence of a comparatively heavy current at high voltage. It may seriously overheat the secondary of a coil or transformer if it is maintained for long, and if passed through the body is likely to prove fatal or extremely dangerous. Precautions against this danger are particularly necessary with transformers or spark-coils operated by alternating currents or by high-voltage mains and mercury or electrolytic interrupters.

If the pressure in the bulb be greater than that of the atmosphere, the spark-length is less than that obtainable in ordinary air, and the discharge is louder and more violently sudden.

If, however, the air be gradually exhausted, most interesting phenomena succeed each other in the following order:—

(1) First, when the pressure is but slightly reduced the discharge still occurs even though the electrodes are separated by two or three times the normal distance. Its form is still that of a spark, though it is quieter and more thread-like.

(2) The discharges broaden until they assume the

form of a thick purplish pink glow which swells in the middle and falls away until it is quite narrow near the electrodes. This glow, known as the *positive column*, fades to nothing near the cathode, which is tipped with violet light known as the *negative glow*.

Between the positive column and the negative glow is a small, ill-defined non-luminous region known as the *Faraday dark space*.

At the same time the conductivity rises to a high value, and only a very small electromotive force is necessary to maintain the discharge.

(3) The positive column expands until it occupies the whole bulb, the negative glow increases and forms a sheath of violet light round the cathode, and the Faraday dark space enlarges.

(4) The positive column breaks up into a series of fluctuating nebulous discs or striæ of glowing gas separated by dark spaces.

At the same time the Faraday dark space enlarges, the negative glow increases in brightness and volume and emits powerful ultra-violet light which excites dark green fluorescence in the glass, and the conductivity decreases. Prof. J. J. Thomson has investigated the potential gradient along the axes of the striæ with most interesting results.

(5) The negative glow detaches itself and moves increasingly far from the cathode, the intervening space being non-luminous.

(6) At still higher exhaustion the green fluorescence disappears and the detached negative glow

leaves a dark space of sharply defined outline between itself and the cathode, upon which a thin violet glow appears.

This non-luminous region, known as the "Crookes dark space," is of the greatest importance, and as exhaustion proceeds the negative glow retires before it until the dark space approaches the limits of the walls of the tube.

(7) The smaller glows at the surfaces of the anode and cathode dwindle, and the chief phenomenon in the interior becomes the dark space, though the walls begin to emit a bright apple-green fluorescent light.

It is noticed that curious non-fluorescent patches are produced on the glass wherever any object such as the anode intervenes between it and the cathode, and that these shadows follow on a magnified scale the general outline of the object as they would do if they were real shadows resulting from light emitted by the cathode; in the meantime the conductivity of the bulb is greatly reduced.

Certain characteristics of the lower vacuum discharge may be mentioned at this point to afford comparison with the discharges in a Crookes vacuum.

If a conductor be brought to the side of the bulb the purple stream (2) is deflected towards it. The stream is, in fact, a column of gaseous molecules which probably pass on electrical charges by acting as carriers, and may be likened to a line of men passing buckets of water from hand to hand to extinguish a fire.

A column of gas conveying charges in this manner

is in many respects equivalent to a stationary conductor carrying an ordinary current; like such a conductor, it is surrounded by circular lines of magnetic force, and on the approach of a magnet it tends to move at right angles to the lines of its field. (See any elementary book on Electricity and Magnetism.)

Thus like a flexible wire the gaseous column in the partial vacuum is deflected on the approach of a magnet to the outside of the tube, and De la Rive has further shown that the stream can be caused to rotate round an insulated magnet placed inside the bulb and lying along its axis, as in Faraday's early experiments with solid conductors.

The purple light of the discharge is accompanied by invisible rays the rate of vibration of which is greater than that of ordinary light, though their nature is otherwise identical.

The electro-magnetic ether vibrations of light range from *about* 400 to *about* 800 billions of complete vibrations per second, the slowest being those of red light and the most rapid (800 billions) being those of violet light. The ultra-violet (beyond violet) light, which is quite invisible, ranges in frequency from *about* 800 billions to *about* 1619 billions per second. The ordinary electric arc and the mercury vapour lamp are both rich in these rays, but we are chiefly concerned with those produced by the vacuum tube.

Ultra-violet light excites vigorous fluorescence in certain materials, and this property is utilised in

ornamental vacuum tubes; sometimes parts of the tube are of uranium glass which fluoresces a dark rich green. Solutions of eosin, uranine, fluorescein, sulphate of quinine, and other substances fluoresce with different colours if exposed to these rays.

Mean Free Path.—The molecules of a gas are in a state of constant and violent commotion, each moving independently with great velocity in continually varying directions.

In hot gases the molecules move with greater velocity than in cold, and it is clear that the average distance which a molecule can travel, without colliding with another, must be inversely proportional to the number of molecules in a given volume of the gas. If this number be halved, the average intermolecular distance, and therefore also the average or mean free path, must be doubled.

The Crookes' Dark Space.—It will be remembered that *at very high exhaustion the dark space occupies the whole of the bulb*; in other words, there is no purple glow throughout the interior.

A possible explanation is that the violet glow seen at comparatively low vacua is caused by the energetic collision of the molecules of gas under the influence of the charges imparted to them, the beginning of the Crookes' dark space showing that the mean free path has become sufficiently long for the "particles" which have been negatively charged at the cathode, or are in themselves charges, to move an appreciable distance from it, before meeting those which are differently charged. If the air be further

exhausted the number of molecules in a given space lessens, and the mean free path is consequently longer, the result being that the collisions occur at a greater distance from the cathode, and the glow which they cause is correspondingly further away. Such explanation, however, must be accepted only with extreme caution, especially in view of the recent developments in the theory of the Crookes' tube. It is found, as might be expected, that the boundary between the dark and the glowing spaces is very brightly illuminated, and it is supposed that in this region the highly charged "particles," moving away from the cathode with enormous velocity in straight lines, first meet those which are moving chaotically.

When the mean free path becomes longer than the distance between the kathode and the wall of the bulb, very little collision takes place; what there is, is more generally distributed, and the dark space fills the whole interior of the bulb, the luminous gas being reduced to a faint blue cloud which, as the exhaustion is carried still further, retires behind the anode, eventually vanishing altogether.

During the stages of exhaustion described the resistance of the bulb to the discharge falls to its lowest value, and commences to rise again, until at a vacuum even higher than any we have at present considered, no considerable discharge can be forced through the bulb, even by the highest electromotive forces.

The dark space having spread as far as the walls

of the tube, the particles proceeding from the cathode meet with no serious obstacle until they strike the glass of the bulb, but a new set of phenomena, of greater interest and beauty than any yet encountered, is presented.

Cathode Rays.—These phenomena were thoroughly investigated by Sir William Crookes in a series of intensely interesting experiments which opened up a new field of research, and paved the way for Röntgen's discovery in November 1895; and it has been thought strange that Sir William Crookes, Prof. Lenard, and the investigators immediately following them, did not discover X-rays, which were frequently produced in a greater or less degree in the course of their experiments. Nevertheless, it was only during the latter portion of the sixteen years which elapsed between the discoveries of Crookes and Röntgen that experiment and research led finally to the publication by Röntgen of the account of his new rays.

A brief outline must serve to include the more important experiments which intervened between the work of Sir W. Crookes and that of Professor Röntgen, but before proceeding a few necessary terms must be explained.

For **fluorescence** and **phosphorescence** see alphabetical list of definitions, p. 8.

A **Crookes' tube,** so called because the word "tube" had come to be the generic term for all exhausted glass vessels arranged for studying the discharge of electricity through rarefied gases, may be

either straight, bent; bulbous, or of any other shape that may be suitable for particular experiments.

The *essential* of a Crookes' tube is the exhaustion to such a degree that the dark space occupies the whole of its interior, all the phenomena of any importance being produced by a stream of negatively charged "particles" moving outward from the cathode, with enormous velocity, in lines which are perfectly straight under normal conditions.

Cathode Rays is the term applied to this stream of charged "particles," which is also alluded to as the cathode stream.

Fluorescence.—It has been shown that wherever the cathode stream impinges on the glass wall of the bulb, its energy is converted into light. In other words, it causes fluorescence. The light given out under the action of this "bombardment" is dependent upon the chemical constituents of the glass, uranium giving dark green and lead-glass blue.

Crookes' tubes, however, are usually constructed of soda-glass, which gives a bright apple-green fluorescence, the total light emitted by a large bulb being often considerable. Though other kinds of glass are occasionally used, a canary-yellow or apple-green light emanating from the bulb itself is an infallible sign of conditions attaining or approaching those which characterise a Crookes' vacuum, while an *almost* total absence of illumination in the residual gases in the bulb indicates a high degree of vacuum approaching that employed in X-ray bulbs.

Many materials of a mineral nature fluoresce when mounted in the direct path of the cathode stream, and some of the effects so produced are among the most beautiful that physical research has given to us.

It must be remembered that fluorescence is actual conversion of the energy given up by the cathode stream as it impinges upon the bodies placed in its path. The effect is one of primary luminous generation, and the colours produced, which depend on the frequency or wave-length of vibration excited in the material, have no relation to the natural colour of the substance. Some of the most beautiful effects are produced by materials which are ordinarily perfectly white.

Diamonds do not always emit the same colour, but one mentioned by Sir W. Crookes gave a brilliant green light.

Rubies, which are crystals of alumina, fluoresce a deep rich crimson, even if the specimens employed are quite colourless. Sir W. Crookes showed that precipitated alumina gave the same rich red as its aristocratic relative and that after continued action the powder assumed a permanent pink tinge and became possessed of certain properties identical with those of crystalline alumina, suggesting that the continual jostling by the cathode stream had worried the alumina into a different molecular arrangement —had perhaps even tidied it up into some degree of crystalline respectability.

Dolomite, a double compound (magnesium car-

bonate and calcium carbonate), shines red, and has the appearance of a piece of glowing coal.

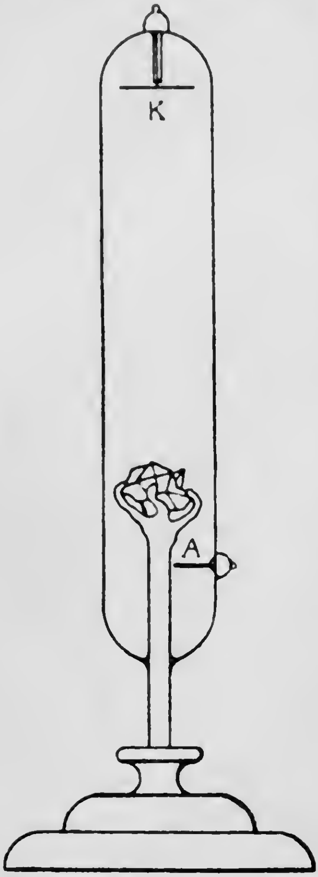


Fig. 1.—Common type of Crookes' tube for exhibiting fluorescence excited by radiant matter.

Willemite (mineral silicate of zinc) gives an intense green light, sometimes of two or three candle-power, zinc sulphide emits a similar but somewhat darker green, and many other minerals fluoresce in various hues. A common whelk shell carefully calcined by ignition gives most beautiful and delicate blues, greens, and pinks according to the nature of the chemical impurities retained on various parts of its surface.

Fig. 1 illustrates a type of tube arranged for showing the fluorescence of one large piece of mineral held in a claw of glass. Sometimes the glass supporting stem has three or four branches each supporting a separate piece of mineral.

Many materials (sometimes the glass of the bulb) continue to glow or phosphoresce with a pale light after the discharge has ceased.

Cathode rays travel with enormous velocity, and

behave in many respects as torrents of projectiles would do.

That they move outward from the cathode *in perfectly straight lines* has been well shown by means of a V-shaped tube with a disc electrode at each end. On making the right-hand disc the cathode, the whole of the right-hand portion of the tube *up to the bend* is rendered fluorescent; if the current be reversed, the left-hand portion of the tube is illuminated up to the bend, while the other arm of the V remains dark.

Magnetic Deflection of Cathode Rays.—It has been explained that the purple stream in a vacuum tube of comparatively slight exhaustion can be deflected by the approach of a magnet to the side of the tube, the deflexion occurring only where the magnetic field crosses the path of the stream, which resumes its former direction when it has got beyond the disturbing influence.

This stream behaves like a flexible conductor carrying a current from the positive electrode to the negative; it is pulled aside by the magnet but *returns to the easiest path between the two electrodes.*

In a Crookes' tube, however, the cathode stream is bent down in a curve which resembles the trajectory of a projectile drawn out of its otherwise straight path by the earth's gravitational force. In fact its behaviour is that which would be expected of a stream of particles possessing momentum and subjected to a transverse force.

The dotted line in fig. 2 (*a*) shows the deflection of the low-vacuum stream under the influence of a horse-shoe magnet placed beneath it; fig. 2 (*b*) shows the path of a pencil of cathode rays under the influence of a similar magnet, the change of direction making itself evident by a new place of illumination

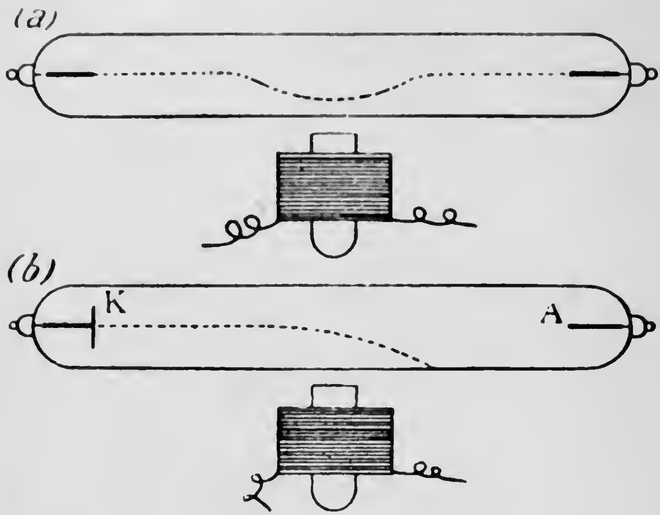


FIG. 2.—Effect of a magnetic field on the directions of deflection of—
(*a*) A *conducting stream* of gas at a comparatively low vacuum.
(*b*) A stream of *negatively charged particles* thrown off from the cathode at a high velocity.

on the wall of the tube. The whole path can be shown by allowing the stream to graze along a strip coated with fluorescent material.

Again, two cathode streams moving in parallel paths as independent streams will diverge, an effect which has its counterpart in the repulsion between parallel wires carrying currents in the same direction.

Another influence capable of deflecting cathode

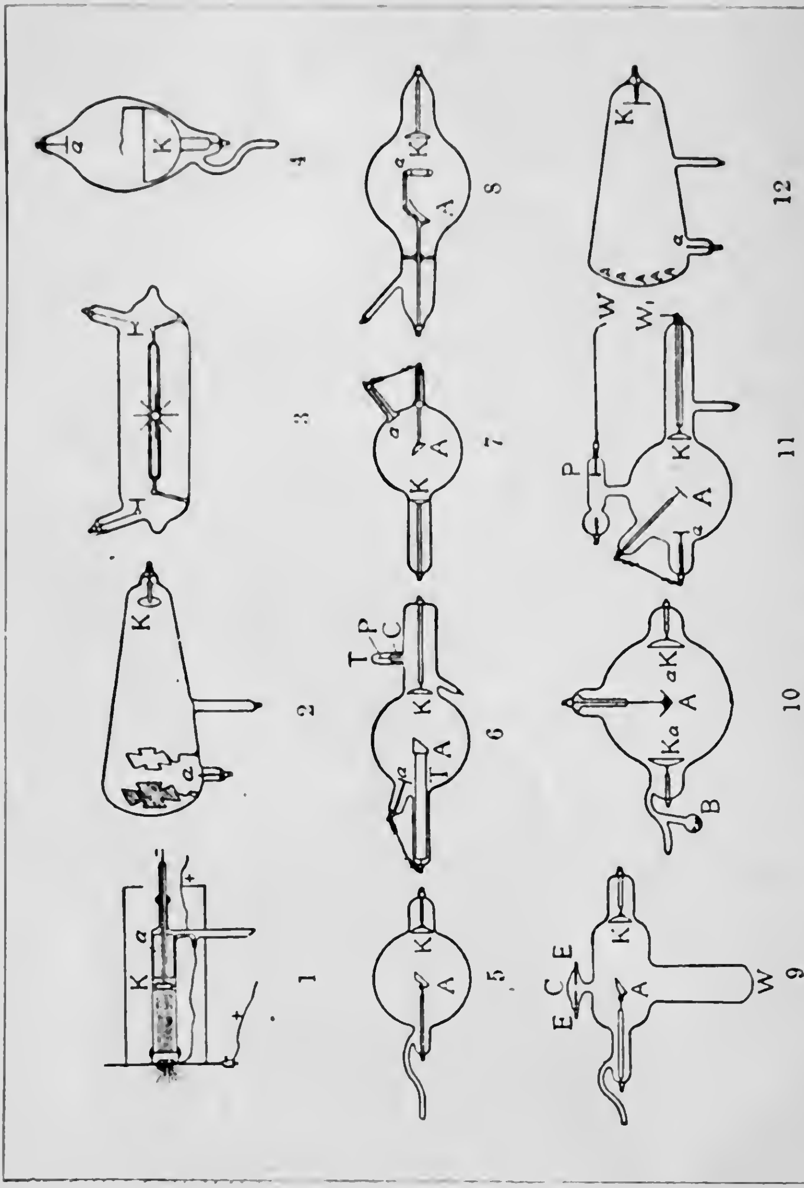
rays from their straight course is electrostatic attraction or repulsion (see list of definitions) by neighbouring charged bodies, but the effect is not very easy to demonstrate.

Apparent Recoil.—Tubes have been constructed with cathodes having four vanes, all coated on the upper surface with mica so that the under surface gives off the cathode stream, the anode being placed for convenience at the top of the bulb. The vanes are placed at the ends of wires projecting from a central pivoted boss, the appearance of the bulb being not unlike that of a Crookes' radiometer. When the discharge is passed the cathode rays are thrown off from the bare sides of the vanes, and cause rotation such as they would experience if there were a recoil effect at their uncoated faces.

Mechanical Effect of Cathode Stream.—The effect which can be produced by the apparent mechanical momentum-energy of the cathode stream is more directly shown by the tube illustrated in fig. 3, Plate I., where the cathode stream impinges upon the upper half of a small wheel of mica vanes running on glass rails. By reversing the discharge at the right moments the wheel may be made to run in either direction.

The effect is further illustrated by placing in a tube four metal plates, equally spaced, above a pivoted, horizontal disc of mica. The plates are sloped at an angle of 45° so that the cathode stream proceeding from them strikes down on the plate obliquely, like rain in a high wind. The energy delivered has thus

PLATE I.



RÖNTGEN RAY AND CROOKES' TUBES.

K—cathode; A—anticathode; *a*—anode.

two components, one acting vertically downwards and probably producing heat and fluorescence, the other being partly expended in producing rapid rotational movement in the disc. A most beautiful appearance results from previously dividing the disc into quadrants painted with different fluorescent minerals, which cause quivering and shifting colours until the rotation becomes so rapid that they blend.

Heating Effect.—Recent researches scarcely leave room for the old theory that these effects were due to the direct mechanical impact of molecular or atomic masses moving at high velocities; it is probable that the forces result from heat generated by the impact of the rays and acting upon the vanes as it does in its radiant form in a Crookes' radiometer.

The magnitude of the heating effect is strikingly illustrated by a tube made as shown in fig. 4, Plate I. The cathode is a large cup of aluminium, which acts in accordance with the following principles:—

It has been shown that the particles thrown off from the cathode tend to follow paths nearly at right angles to its surface, and in ordinary Crookes' tubes the tendency is very strong, though it ceases to be true when X-ray vacua are reached.

It follows that rays proceeding from the whole interior surface of a cup-shaped cathode in straight lines normal to that surface must form a kind of focus where they meet and are concentrated. This focalisation must not be confused with that obtained by the reflection of light, heat, sound or Hertzian

waves from parabolic or spherical mirrors, as the cathode rays actually come into being at the surface of the cup.

To the edge of the cup, fig. 4, Plate I., a small piece of platinum foil is attached by an upright support so that it lies eccentrically at a short distance on one side of the focal point of the cathode stream. The discharge from an induction coil through the tube leaves it cool until the cathode stream is deflected on to it by a magnet, when it quickly gets red or white hot, or even melts; two properties of radiant matter are thus simultaneously illustrated.

For lecture demonstration, Sir William Crookes placed in a lantern a small Crookes' tube with a concave cathode arranged to send the focussed beam along the axis of the tube. The undisturbed rays came to a focal point just above the cathode without noticeable results; but on deflecting the stream to the glass walls of the tube, so that the bent rays were focussed thereon, a coating of wax on the outside of the glass was first melted, then small cracks appeared until the heated glass finally collapsed, admitting the atmosphere and destroying the vacuum.

The dotted lines in (*a*) and (*b*), fig. 3, show respectively the path of the rays when undisturbed, and when deflected by the magnet.

The thermal effect of the focussed stream is of great importance in X-ray work, and gives rise to practical troubles which are considered hereafter. The temperature at the point of impact of a cathode

stream is capable of converting diamond into amorphous carbon and of melting osmium, tantalum, and tungsten, an operation which requires something like 3000° C.

Cathode-Ray Shadows and Fatigue.—An object

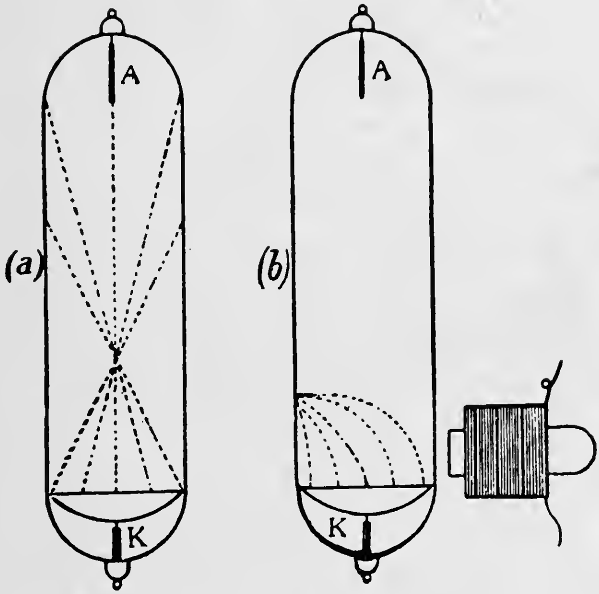


Fig. 3.—Experiment for showing the fusing of the glass wall of a Crookes' tube by a magnetically deflected, focussed cathode stream.

placed in the path of the cathode stream cuts it off, and a "shadow" or non-fluorescent area is produced on the walls of the tube or on any screen of fluorescent material placed therein. If the object be at some distance from a small cathode and fairly near the tube-wall or the screen, very sharp "shadows" are obtained.

The beauty of the "railway" tube, previously described, is greatly enhanced by the remarkable play and movement of the fluorescence on the glass walls as the rotating vanes alternately stop the stream and allow it to pass.

Fig. 2, Plate I., shows a tube (often as much as 10 in. in length) with a cathode at the small end and a mica cross near the large and slightly curved front. The cross is attached to its support by a small hinge, and can be shaken down out of the path of the cathode stream. When the cross is erect and the discharge passing in the right direction a non-fluorescent shadow is cast, all the surrounding glass at the large end being brightly illuminated with the characteristic apple-green light. If, after leaving the current on for a few seconds, the cross be shaken down and the discharge started again, the previously shadowed cross-shaped area becomes more brilliantly luminescent than its surroundings, showing that the glass has partially lost its fluorescing power, and exhibits a species of "molecular fatigue" such as occurs in materials subjected to mechanical strain, etc.; this effect has been wrongly attributed to the heating of the unshadowed glass.

Fluorescence fatigue of the glass occurs in X-ray tubes, but does not involve any deterioration, and, if anything, is advantageous, as less energy is absorbed in producing light-waves over the area of impact on the glass. Moreover, a decrease of luminosity in the bulb renders screen-work easier. (See Chapter on X-ray Bulbs.)

Electric Charge carried by Cathode Rays.—M. Perrin (*Comptes rendus*, 121, p. 1130, 1895) and Prof. (now Sir) J. J. Thomson (*Proc. Camb. Phil. Soc.*, ix., 1897) have made experiments which show that cathode rays convey a considerable negative charge, and can give it up to a body which they strike, and Sir J. J. Thomson succeeded in deflecting them by means of an electrostatic field.

Cathode Rays in Air.—The experiments made by Professor Lenard in 1894 show that the cathode rays can pass through a thin aluminium disc, and that if such a disc is employed as a window to a Crookes' tube they will emerge into the air. The supposition among English scientists was that their power of penetration was imparted to them by the velocity and momentum which they were supposed to gain in the bulb.

In Lenard's tube, fig. 1, Plate I., the cathode K is an aluminium disc connected with the negative terminal of the induction coil by the platinum wire (marked —) which is fused into the end of the tube. The anode *a*, a brass cylinder fitting tightly into the main glass tube and terminating 12 mm. behind the cathode, is connected with a wire which is fused into the glass and outwardly joined to both the outside case and the earth.

At the left-hand end is a metal covering cap pierced by a small hole over which a very thin aluminium disc is cemented with marine glue. The disc and cap are in metallic connection with each other and with the wire. To prevent the aluminium

window from acting as an anode, and becoming corroded, it is screened at the back by a perforated metal cover. The whole tube is enclosed in a metal case provided with an opening opposite to the window, and earth-connected (see above).

When such a tube is in action, the path of the rays is seen as a faint brush-like glow spreading outwards in the directions indicated by the lines in the figure to a distance of about 5 centimetres; this has been attributed to the collision of the issuing radiant matter with the molecules of the air. By exploring the field in front of the tube with a screen of fluorescent material, Lenard showed that after passing through the aluminium the cathode rays spread out much as light spreads in a cloudy substance such as smoke, milky water, or opal glass. This was demonstrated by observing the shadows cast by metallic wires at varying distances between the window and the screen.

With the screen at 3 cm. from the window, a wire 2 mm. thick cast no visible shadow. As the wire was brought nearer to the screen a shadow appeared, but was not well defined until they were in contact.

Professor Lenard also showed that the fluorescent patch on the screen was brightest at the centre, and in fact had much the same general appearance as the patch produced by a beam of light after passing through a trough of milk. This he took to be a proof that the rays had actually passed through the aluminium and were not produced at the outer

surface of the plate by some action conveyed from within.

Many substances were rendered fluorescent by the Lenard rays, including calc spar, the phosphides of the alkaline earths, various kinds of glass, quartz rock salt (fluorescence blue), alumina produced by corrosion of aluminium, various platino-cyanides and several salts of organic and inorganic origin. Many of these substances also phosphoresced brightly. The best screen was made by painting with a brush on tissue-paper, melted pentadekylparatoleketone, which gave bright green fluorescence.

Liquids such as fluorescein, Magdala red, sulphate of quinine, etc., which all fluoresce in ordinary light, showed no effect whatever, though quinine in the solid state gave a brilliant blue.

The rays penetrated through gold, silver, and aluminium foil; two thicknesses of tissue-paper showed a faint shadow; writing paper showed a distinct diminution of the rays; and cardboard 3 mm. thick was quite opaque. Water was only transparent when in very thin layers, but gases were comparatively transparent.

The external cathode rays observed by Lenard were abundantly mixed with the yet undiscovered Röntgen rays, though the silhouettes he produced on photographic plates were probably partly due to real cathode rays. That the phenomena were not wholly caused by X-rays is proved by the fact that he passed the radiation into a second tube, also exhausted, and there deflected it with a magnet,

which is impossible with Röntgen rays. This short sketch of Professor Lenard's experiments is drawn in the main from Mr Hyndman's most interesting book *Radiation*, and from Professor J. J. Thomson's works.

The Nature of Cathode Rays.—In the foregoing account cathode rays have been described as streams of charged "particles" thrown off by repulsion from the cathode, and travelling at enormous velocities. All their effects have been explained on this hypothesis, but the properties of Lenard's external cathode rays, and the mere fact that they can be brought outside the tube, have led many physicists of eminence to consider them as some kind of disturbance of the æther.

Generally speaking, the English scientists have adopted the radiant-matter or corpuscular theory originated by Sir W. Crookes, while the Continental explanation was æthereal. It is to the Continental scientists that we owe the term "Cathode Ray," and though it was used by them in contradistinction to Crookes' name—"Radiant Matter," it has gradually made its way into England, where it has been generally accepted.

One of the arguments brought forward by the supporters of the ætheric theory is that radiant matter could not penetrate the aluminium window of Lenard's tube, and to overcome the difficulty it was suggested that the radiant matter strikes the inner surface of the window, inducing Lenard's rays on the outside. In view of the nature of some of

the effects obtained by Lenard, it is impossible to accept this except as more than a partial explanation; moreover, Professor J. J. Thomson always thought it unnecessary to assume that the molecular stream is incapable of penetrating the window.

Mechanical effects were explained by Continental scientists as of a secondary nature, and thermal effects were attributed to direct conversion of the energy of the ætherial disturbance into heat.

By using external electrodes acting on the interior of the tube by electrostatic induction, Sir W. Crookes proved that the stream did not consist of metallic particles torn off and projected from the cathode. Metal can be torn off in considerable quantities from internal electrodes, but there is no possibility of making it responsible for the main effects.

The experiments of Hertz and Lenard were held by leading German physicists to be proof that the rays were in the nature of ætheric vibrations like light and other electromagnetic waves. The corpuscular theory supported in England has held its own, though it had eventually to be modified, electronic being substituted for molecular or atomic conceptions. Long before the actual triumph of the corpuscular over the ætheric theory, Sir William Crookes foreshadowed it by the far-seeing suggestion that the rays consisted of matter in a fourth state—finer and subtler than the lightest and most palpable gas imaginable.

In 1898 it became known that Sir J. J. Thomson, with the wonderful insight, accuracy, and constructive

ingenuity which have characterised all his researches, had deflected the cathode rays by magnetic and electric fields of force, and had proved by his subsequent measurements and calculations that the mass of a constituent particle in the cathode stream is only about $\frac{1}{1800}$ of that of a hydrogen atom, which had previously been looked upon as the smallest mass capable of individual participation in any chemical or physical action.

The Electronic Theory of Matter.—Such ideas and discoveries provided the foundations upon which was built the electronic theory of matter; for we must now conceive of the cathode ray as a stream of corpuscles of electricity moving at velocities varying from 6000 to 60,000 miles per second, and of dimensions so minute that one contained in a hydrogen atom is as a speck of dust in a room.

Furthermore the atom of matter, unthinkably minute as it is, must be considered as a definite grouping of electrons in constant motion, yet so widely separated that a hydrogen atom with its 1830 electrons would be represented by a sphere having cubical content equal to that of a cathedral and containing 1830 flies.

Again, if the inconceivably small molecule itself could be expanded to the size of a cricket-ball, its constituent electrons being enlarged in proportion and endowed with the power of affecting the eyes as isolated objects when sufficiently magnified, a powerful microscope would still be required to enable a human being to distinguish the individual electrons.

Röntgen's Discovery.—In 1895 Professor Wilhelm Konrad Röntgen announced his discovery of a new kind of radiation capable of penetrating considerable thicknesses of substances which are quite opaque to ordinary light.

Many were at first incredulous, especially those with some knowledge of physics who were nevertheless unacquainted with the more recent researches on cathode rays. Their scepticism was the natural outcome of journalistic ignorance and gullibility, which, in the case of at least one highly modern newspaper, has been so frequent and gross that it has become a traditional source of amusement to scientific readers.

Professor Röntgen found that when using Crookes' tubes of unusually high vacuum certain rays emerged from the tube and, unlike the cathode rays, were not deflected by a magnet. Photographic plates were affected by the new rays, and shadow-pictures, now called radiographs, were obtained by exposing to the radiation plates protected from ordinary light and having opaque objects between the film and the source of the rays.

Röntgen's radiographs were not excelled for some time after the publication of his results. He ascertained the comparative radiability of various substances, and found that wood, paper, leather, celluloid, certain kinds of glass, diamonds, etc., were almost transparent to his "X-rays," that bone, lead-glass, and other substances were semi-opaque, while the opacity of metals seemed roughly propor-

tional to their atomic weights, aluminium being highly radiable, and lead or platinum almost opaque. He also made radiographs of the bones in the hand, etc., and, appreciating the importance of this achievement, at once communicated his results to a great German physico-medical society.

Fluorescent Screens.—Röntgen also experimented on fluorescence, and mentioned screens made of barium-platino-cyanide, which rendered visible the shadows of opaque bodies. In fact, the discovery preceded that of the actinic effects.

The many radiographs published shortly afterwards in England by Mr Campbell Swinton and others concentrated public attention on this aspect of the subject, and the use of fluorescent screens was largely neglected.

Edison made exhaustive experiments on the fluorescence excited in different materials by the new rays, and sent a telegram to Lord Kelvin to the effect that sheelite (calcium tungstate) was superior to any platino-cyanide.

The news was immediately spread in England (by the daily press of course) that Mr Edison had discovered a method of "seeing" the bones by X-rays, and the scare headlines predicted the abolition of all privacy by the use of "cameras" outside closed rooms.

Röntgen was the true inventor of the fluorescent screen, which really shows *shadows* or non-fluorescent areas similar to that produced by the cross in the "radiant matter" tube (fig. 2, Plate I.).

Calcium tungstate has *not* proved superior to barium-platino-cyanide for ordinary purposes, though, as will presently appear, it has its uses.

Production of Röntgen Rays.—*Wherever cathode rays strike a solid body they produce Röntgen rays,* which, if the body is transparent to them, pass through it and emerge on the other side as well as being radiated from the surface exposed to their impact.

Early Tubes.—In the early type of tube illustrated in fig. 12, Plate I., the rays originate where the cathode stream from the aluminium disc at the small end strikes the surface of the glass at the large end. If the stream is powerful the glass is easily melted, and in any case the area of radiation is so great that sharply defined shadows cannot be obtained. Nevertheless the results were remarkably good, considering the faults of the appliance.

The Focus Tube.—In 1896 a fundamental and important improvement was introduced almost simultaneously by Professor Elihu Thomson, Mr Shallenberger, Mr Scribner, and Professor Herbert Jackson of King's College. The latter is generally credited with the first use of the focus tube, at least in England, and it was for some time known in this country by his name.

It is illustrated in fig. 5, Plate I., where K is a concave aluminium cathode which directs a cone of cathode rays to a concentrated focal point on the anodal target or anti-cathode A (see Chapter on X-ray Bulbs). At the point of impact the X-rays

are generated, and as the target is of platinum or other refractory and opaque metal, it not only stands considerable temperature rise, but it allows but little penetration of the X-rays to its reverse face.

The radiation generated at A proceeds radially outwards in all directions, and as A is placed at an angle of about 45° with the axis of the tube, the rays are directed towards the thin soda-glass of the bulb and emerge without encountering any considerable opposition.

The dotted lines in fig. 4 show the direction of the cathode stream, and the dot-and-dash lines the paths of the Röntgen rays.

The latter induce fluorescence in the glass as they pass out, the colour being canary-yellow or apple-green according to the material of the glass and the degree of exhaustion. The luminosity of the glass exactly coincides with the area exposed to the Röntgen rays. The results obtained with the focus tube accord with the usual inverse-square law for point-source radiation, and radiographic and screen effects are far sharper and more detailed than those obtained with the earlier tubes. An account of different types of tube is given below, and the following is from a short description (due to Mr J. H. Gardiner) of the different stages of exhaustion of a focus tube, commencing with its first production of cathode rays:—

Stages of Vacuum.—(1) The cathode rays are visible as a faint gaseous luminosity focussed in front of the anti-cathode, which is uniformly red-hot.

Considerable gaseous luminescence is seen round and behind the anti-cathode, the dark space is just visible and the resistance is equal to that of an air-gap between points separated by about $\frac{3}{4}$ in.

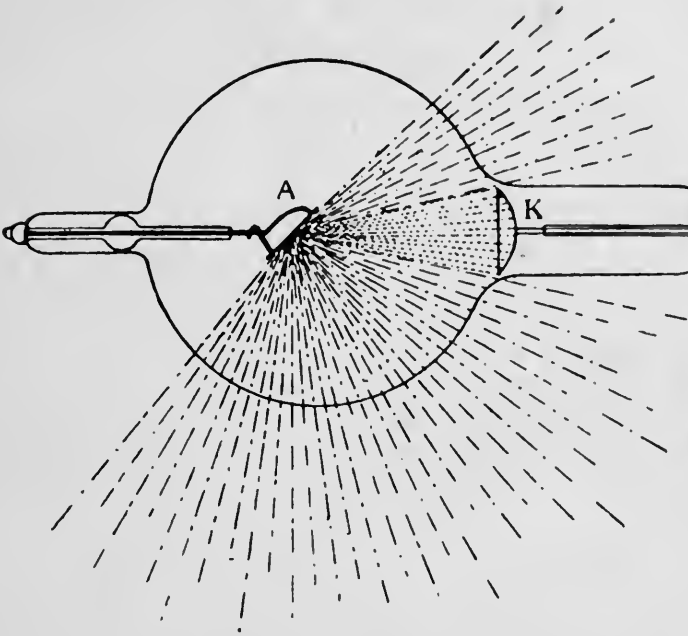


FIG. 4.—Directions of the cathode stream (dotted) and X-rays (dot and dash) produced in a focus tube.

(*Note.*—The X-rays pass through the space occupied by the cathode stream, and have only been omitted there to avoid confusion.)

(2) The cone of cathode rays is fainter and focuses at a greater distance, producing a bright red spot on the dull red surface of the anti-cathode. The glass-fluorescence is greater and there is less gaseous luminosity. Resistance $= 1\frac{1}{4}$ in. of air.

(3) The cone of rays is invisible, there is a faint

nebulous glow in front of the anti-cathode, the fluorescence is more brilliant, and the resistance $= 1\frac{3}{4}$ in. of air.

(4) The nebulous glow has crept up the front and over the back of the anode, detaching itself and forming a faint cloud behind it. The fluorescence is at its maximum and the anti-cathode is red-hot at its centre.

(5) There is now a sudden change. All trace of the nebulous cloud has gone, the target is no longer red-hot, the fluorescence has diminished to $\frac{1}{4}$ its maximum intensity, and the resistance $= 4$ in. of air.

During the latter stages of exhaustion the cathode stream, as far as it is visible at all, is seen to diverge to a steadily increasing degree, so that the focus or crossing point is eventually situated upon the anti-cathode.

Mr Gardiner found that the fluorescence excited in a screen increases throughout these stages, while the maximum photographic effect coincides with (4), and is accompanied by the maximum of fluorescence in the glass.

CHAPTER II

PROPERTIES, NATURE, AND USES OF RÖNTGEN RAYS

Reflection and Refraction.—Regular reflection is the reflection obtained from a polished surface in contradistinction to the irregular or diffused reflection yielded by powders, matt surfaces, etc. A ray of light leaves a polished surface according to fixed and known laws which only hold good if the molecular arrangement is such that the roughnesses presented to the ray are small in comparison to the length of the waves of light.

On the assumption that X-rays are extremely short ætheric waves—far shorter than the smallest ultra-violet waves known—it is clear that the polish of a reflector for these rays must be finer by far than anything obtainable with available materials polished by human agency.

The remarkable researches of Professors Lane, Freidrich, and Knipping, and of W. L. Bragg of Cambridge, have shown, however, that reflection and interference take place within the structure of crystals, and the last-named worker succeeded in

obtaining regular reflection from the cleavage surface of mica, which is known to be particularly dense in molecular arrangement.

In attempts at refraction there has been no success, but X-rays share with light their power of reducing the resistance of crystalline selenium. Like light, they also differ from cathode rays in being unaffected by magnetic or electric fields.

Physiological Effects.—The physiological effects are of interest and importance; and though X-rays are not easily visible to the normal eye, they affect the blind under certain conditions. Out of 240 pupils in a blind school, nine were found able to perceive Röntgen and cathode rays as colour, while two experienced a painful sensation; five out of the nine perceived fluorescence rays from a barium-platino-cyanide screen. In all these cases the trouble causing the blindness was peripheral, not central.

The experiments of D. Bossalino show that after prolonged adaptation to darkness and blindfolding the normal and the cataract-afflicted eye are both affected, the shape of metallic objects between the tube and the eye being distinguishable. He supposes these effects to be due to fluorescence of the retina.

E. Dorn found that straight rods sometimes cast bent shadows; he attributes this to the fact that X-rays are not refracted by the humours of the eye, and therefore cast on the retina shadows which correspond to images ordinarily produced by bent rods.

X-Ray Dermatitis.—Before X-rays had been long in use those constantly employing them developed

serious complaints, which in many cases eventually resulted in horrible suffering and the loss of limbs, and occasionally of life. Some of the worst cases were the result of persistent neglect of precautions after the appearance of disease, and at a time when means for its prevention were available.

Fortunately the least penetrative are most dangerous rays, and therefore considerable protection is afforded by clothing and other fairly radiable obstacles. Soft tubes are rich in these rays, and therefore must be used with greater caution than is required with hard tubes.

The trouble generally begins on the back of the right hand, as it is frequently used for testing and viewing X-ray tubes and fluoroscopes; but the face and eyes are also attacked in time, and even clothing is inadequate protection against excessive exposure. Without giving medical details, the progress of the disease may be indicated in a few words :—

First the skin is irritated and feels hot and dry, then blisters and red coloration appear, and are followed by a discharge of yellowish serum lasting for ten days or more.

This is succeeded by ulceration over the surface, which changes to adherent "sloughs" of dead skin.

Eventually there are periods of deep ulceration, which often becomes dangerous and cancerous in nature and involves the removal of fingers.

The earlier stages are marked by violent irritation, and the later by severe pain.

A characteristic feature is the formation of hard,

warty nodules and a general thickening of the skin, which in time may develop deep cracks at the knuckles. These cracks, and the absorbent character assumed by the skin, make it an easy prey to septic poisoning, which may easily involve the arm and entail amputation. The hair is also destroyed, and the nails become scaly and fall off.

Sometimes healing takes place after a year or more, but generally the disease proves incurable, though alleviation is obtained from radium and other treatment. In one case which has been watched with interest by the present author for years, the injured hand has been operated upon and treated by most known methods, and, although it has been protected from radiation ever since it developed seriously, its present condition is not materially improved.

In the early days of long exposures it was not uncommon to meet with cases of dermatitis resulting from single exposures made for surgical purposes, and in a few cases there were symptoms resembling those of sunstroke, *i.e.* vertigo, headache, sickness, sight dimness, and entire prostration.

There are various deep-seated actions, and the normal functions of certain organs seem to be injuriously affected by prolonged and careless exposure to the rays.

Beneficial Effects of X-Rays.—Certain diseases are undoubtedly cured and others are alleviated by exposure to X-rays, but want of space excludes anything more than a reference to the medical aspect of the subject.

Secondary Rays.—Secondary X-rays result from the incidence of X-rays upon the surface of many substances, and their extent varies considerably according to the nature of the substance.

The secondary rays are largely of the same nature as those which excite them, and may be looked upon as the original rays scattered and diffusely reflected very much in the same way as light is scattered by fog. Improved definition and detail have even been achieved in radiography by the use of stops and tubes of glass or metal to cut off the scattered radiation emitted by the large area of glass which is excited by the rays before they leave the bulb.

The Nature of X-Rays.—The nature of X-rays was for long the subject of conflicting theories and suggestions; for instance, they have been held to be streams of material particles, longitudinal ætheric vibrations like sound-waves in air, aperiodic or pseudo-wave impulses like explosive sounds in air, and also ætheric waves of far higher frequency and shorter wave-length than any other known radiation. Recent discoveries in connection with the passage of X-rays through crystals have strongly established the last of these theories and enabled physicists to estimate the wave-length and frequency.

The results give for X-rays a wave-length of about 10^{-8} cms. and a frequency of about 3 million billion vibrations per sec., or nearly 40,000 times the rapidity of vibration of violet light.

The Uses of X-Rays.—Besides the surgical uses

in diagnosis through radiography or radioscopy, and the medical treatment of disease, there are few practical applications of X-rays.

Flaws can be found in castings, but the method is not of practical importance. Precious stones can be distinguished from paste, ruby, emerald, and diamond being more transparent than their imitations, while pearl is less so; but even here the methods known to jewellers are effective and more convenient.

It is easy, according to Dubois, to locate pearls in oysters in spite of the opacity of the shells, and the process is employed in the Ceylon fisheries to avoid waste and thinning of the beds.

In biological and anatomical study X-rays are of course invaluable.

CHAPTER III

APPARATUS FOR THE PRODUCTION OF SUITABLE DISCHARGE

THE foregoing pages show that the source of supply to the tube must be of high electromotive force, and that for satisfactory working the source of supply should be truly unidirectional.

The Induction Coil.—The induction coil is undoubtedly the best high-voltage appliance, and though radiographs can be taken with coils giving 1-in. spark and less, they are inadequate for serious work. A 2-in. spark coil gives good results though with long exposures, a 3-in. works well, and a 6-in. coil can be used with comparatively hard tubes. Few cases require anything much larger, though heavier discharges increase the penetration and reduce exposures.

It should be remembered, however, that what really matters most is the average value of the current through the tube, and the higher this is the shorter will be the exposures; the advantage of coils giving long sparks is mainly in their ability to overcome the resistance and back electromotive force

of the tube. Indeed, there is no limit to the current which may be passed through a tube except that of safety for the tube itself.

The long-delayed realisation that for Wireless as well as X-ray work a heavy discharge is far more important than a long spark has brought about modifications of design in the following directions:—

The iron core is larger and heavier than formerly, and is made up of laminæ instead of round wire. The finest modern iron is used, and in some cases. the maximum possible space is filled by it as a result of using comparatively thick plates of highly resisting magnetic alloy, which greatly reduces eddy-currents.

The primary winding is of many turns of thick wire capable of carrying the heavy currents taken from high-voltage lighting mains, and is commonly arranged so that the layers can be connected in parallel or in series according to circumstances.

The art of constructing condensers has advanced immensely in recent years, but with modern interrupters the importance of this appliance has diminished. Mercury interrupters working with gaseous dielectric need very little capacity, while Wehnelt and allied breaks interrupt the current so suddenly and completely that the condenser can be dispensed with. The secondary winding is of heavier gauge, wound with less of the elaborate care for insulation during the process, which at one time made the work very tedious, and instead the finished winding is impregnated with wax so efficiently by

exhaustion in vacuum-ovens that the final insulation is greatly superior to anything formerly achieved.

A commutator is a valuable but not essential accessory to the coil.

Platinum Interrupters.—Certain high-speed platinum interrupters now on the market are useful for occasional and temporary work, but the heavy renewal costs are prohibitive for extensive use, and such interrupters compare unfavourably with other types.

Mercury Interrupters.—Far better results are obtainable with good mercury interrupters than with platinum contacts, and the so-called "turbine" type makes it possible to employ comparatively high voltages for the primary of the induction coil; the circuit can consequently be interrupted with great rapidity, the time necessary for the magnetic saturation of the core being much decreased. The resulting torrent of sparks, usually thick and hot, is ideal for X-ray work, and when the tube is substituted for the spark-gap the tube-current reaches a high average value.

Further information about mercury interrupters is given on pp. 90–95 and 97–98 of the author's *Wireless Telegraphy for Amateurs*, 3rd edition (Percival Marshall & Co.), and more fully in *X-Rays*, by Dr G. W. Kaye, pp. 62–66.

The Wehnelt and Caldwell-Swinton Breaks.—These produce very heavy discharges of high frequency, and in X-ray work give brilliant screen-effects and short exposures. They must, however, be used with caution unless a special heavy-current tube is used.

For the construction of mercury and Wehnelt breaks reference must be made to articles in the *Model Engineer*, vol. iii. p. 2, Jan. 1900, and vol. vii. p. 209, Nov. 1902.

Sources of Supply for Coils: — Accumulators, Primary Batteries, and Dynamos. — Continuous-current dynamos and accumulators or secondary batteries are in every way superior to other sources of current for induction coils, as serious X-ray work makes great demands on the source of supply, and the taking of one or two radiographs soon exhausts a small primary battery.

Accumulators are far less troublesome than primary batteries, if there are convenient means for charging them. They can be obtained in portable form, and have a low internal resistance and a high E.M.F. cell for cell. On the other hand, primary batteries need not be taken away for charging, and *if* only a small amount of work is required of them they are cheaper than accumulators.

Where a continuous-current lighting circuit is at hand accumulators may be used, but it is far better to employ the supply mains themselves in conjunction with a mercury or Wehnelt interrupter, and if necessary a variable resistance. Large coils can thus be energised from circuits at voltages as high as 250. Turbine interrupters are even made with synchronous motors for use on alternating-current circuits, and are arranged to give unidirectional secondary discharges.

If primary batteries must be used, the bichromate

or chromic acid cell is perhaps best, or, if the expense is not too great, the Edison-Lalande.

Though the latter gives a low electromotive force, necessitating the use of a large number of the cells in series, its internal resistance is very low and the ampère-hour capacity is high. (See *Small Accumulators*, Model Engineer Series.)

Wimshurst Machines.—Influence machines are in some respects superior to induction coils, especially in countries where there is not much atmospheric moisture, and the fluorescent-screen effects produced by powerful machines are wonderfully brilliant.

It is difficult to be definite as to the minimum size of Wimshurst which will produce radiographs, though quite respectable specimens produced by $\frac{3}{8}$-in. spark machines have been published. The sparks given by different Wimshurst machines vary in quality; some which are short and thick result from the discharge of a considerable quantity of electricity at a comparatively low electromotive force, others which are long, purple streaks indicate the discharge of a small quantity at high electromotive force.

The size of the small Leyden jars often supplied with such machines is an important factor, but, broadly speaking, any Wimshurst giving fairly frequent sparks 2 in. long will do good radiographic work, though it may prove somewhat inadequate for screen-illumination.

The machine should be carefully selected, and the plates should be of alkali-free glass, unvarnished.

A large machine with several plates usually gives

the best results when connected directly to the tube, but with small machines it is better to insert a small spark-gap between each terminal of the machine and the corresponding terminal of the tube (see Chapter on Radiography). Experiments in any given case soon show which arrangement is more satisfactory.

The continuous occupation of one hand in working a Wimshurst machine is hampering and wearisome, and the results are variable; but a suitably geared motor with a controlling rheostat removes these difficulties.

Generally speaking, influence machines must be large and probably expensive if they are required for constant work demanding any considerable output.

Tesla Coils.—When a Leyden jar suddenly discharges across a spark-gap through one or more turns of wire capable of producing a magnetic field and therefore having self-induction, the spark is oscillatory, that is, it consists of rapid and successive reversals or alternations of current which decrease in strength until, like the vibrations of a disturbed spring, they die away. The frequency of vibration may easily reach a million per second.

If such a discharge be sent through a special transformer called a Tesla coil, oscillatory currents are induced therein at a greatly enhanced electromotive force, which renders the production of X-rays possible when the induction coil by itself would be inadequate.

This method, however, cannot be recommended, as

the reverse currents through the tube are as objectionable as those obtained with ordinary alternating currents.

A special double cathode tube for use with Tesla coils is shown in fig. 10, Plate I., but for various reasons its use has not become general.

CHAPTER IV

RÖNTGEN RAY TUBES

The tube or bulb used for the generation of X-rays is so important that it is worth while to deal at some length with the general and particular principles of construction, and the physical properties and phenomena which occur in it.

A description of the manufacture of X-ray tubes is not attempted, as such work is beyond the scope of the ordinary amateur.

Fig. 5, Plate I., shows Jackson's focus tube, used with no *fundamental* departure in type up to the present time.

In such a tube the primary factor, which determines its behaviour in given circumstances, is the resistance offered to the passage of the discharge. If this is relatively high, the rays have great penetrative power, passing easily through bones and producing "flat" radiographs—wanting in contrast. A tube of relatively low resistance produces feebly penetrative rays which are almost stopped by the flesh as well as by the bones; in radiographs the latter appear nearly black, with little or no structural detail.

Between these extremes there is a wide range for choice, and a tube that is good for one class of work may be almost useless for another.

Soft and Hard Tubes.—Tubes which are soft and feebly penetrative, and those of high resistance and penetration, are distinguished by the terms "soft" and "hard." The resistance, though chiefly governed by the degree of exhaustion, is also affected by the dimensions and disposition of the electrodes.

The cathode rays having been well called the parents of the Röntgen rays, the cathode, from which they proceed, may receive first attention.

The Cathode.—The cathode (K, Plate I.) is invariably a cup of such curvature that the rays emanating from its surface converge approximately upon a point in the centre of the anti-cathode A.

The curvature is fixed with due regard to the fact already stated, that as exhaustion proceeds the focal point moves away from the cathode until its distance may be four or five times as much as the radius of curvature of the cathode.

A small cathode gives a high resistance and penetrative rays,—a large one low resistance and soft results. Mr Addyman gives about 1 in. diameter as a good size for ordinary work.

The cathode is of aluminium, as the discharge tears off particles from other metals, distributing them over the inner surface of the bulb and thereby discolouring it and increasing its opacity. The surface should be of uniform curvature and well polished. Within certain limits, an increase of dis-

tance between anode and cathode has the surprising effect of decreasing the resistance, and Mr Campbell Swinton has taken advantage of this fact by making the cathode movable, so that by tilting and gentle taps its distance from the anode can be adjusted to the extent of about ½ in.

Steadiness is increased and sputtering reduced by shielding the supporting wires of both electrodes with glass sleeves and disposing the cathode well within the tubular projection which houses its support. Tubes are now made with means for cooling the *cathode*, as this helps to prevent hardening.

The more accurately the cathode-stream converges upon a fine point on the anti-cathode, the sharper and more detailed will be the results. This concentration, however, causes intense localisation of heat, and fusion or even perforation will result unless due precautions are taken. The focussing is never quite accurate in ordinary tubes, but anti-cathodes of platinum and even of tantalum and tungsten soon show local fusion if the current is excessive. Anything which facilitates loss of heat by the anti-cathode naturally renders it less liable to damage by high temperature, and therefore permits more accurate concentration of the cathode stream and greater sharpness in the results; at the same time a heavier discharge and increased radiation are secured.

The Anti-cathode (A, Plate I.).—Much depends on the design of the anti-cathode, which is usually a plate of metal mounted opposite to the centre of the cathode, and inclined at an angle of about 45° with

the axis of the tube. Although the Röntgen rays which emanate from it are definitely directed towards one side of the bulb, it has been shown that the obliquity does not increase the quantity of radiation and has no substantial advantage; in fact, it actually increases the area of emission and lessens the sharpness of definition.

Röntgen soon discovered differences in the emissive power of anti-cathodes of various materials, platinum being greatly superior to aluminium. Finding also that X-rays were either generated at the back face also of the anti-cathode, or, originating at the point of impact, penetrated through to the opposite side, he *maintained that in addition platinum was superior in emissive power to aluminium.*

Having a high melting-point, platinum was for long the substance used for anti-cathodes; but other desiderata govern the selection of the material, and these are given by Dr Kaye as follows: (1) high atomic weight; (2) high melting-point; (3) high thermal conductivity; (4) low vapour-pressure at high temperatures.

Dr Kaye has shown that the quantity of radiation emitted is nearly directly proportional to the atomic weight, and that the material also affects the *nature* of the radiation.

Desiderata (2) and (3) are chiefly important in the avoidance of fusion of the anti-cathode, while (4) secures a minimum of "sputtering," disintegration, and volatilisation.

Of the reasonably available metals, excellent

results are obtained with platinum, osmium, iridium, tantalum, and tungsten; the last-named, with a melting-point of 1750° C., sputters badly and is increasing rapidly in price, whereas tantalum and tungsten are rapidly cheapening, and though their atomic weights are somewhat less than that of platinum, their melting-points are 2900° C. and 3200° C. respectively, while tungsten has about twice the thermal conductivity of platinum. The intensity of radiation of both is about 10 per cent. less than that of platinum, but their good qualities outweigh their disadvantages, and probably tungsten in particular will shortly displace platinum, which was formerly employed almost universally. In many cheaper tubes platinised nickel is used, and is satisfactory so long as the discharge is not enough to fuse the platinum and expose the poorly radiating nickel.

Fig. 5 is from a photograph of a platinum anti-cathode which has been damaged by excessive current. For heavy work tubes have been designed with anti-cathodes of solid copper plated with platinum or provided with means for keeping the back of the anti-cathode continuously cooled by water, by air-currents, or by interchangeable cooling tongs. Others again are designed with a view to running the anti-cathode normally at red heat.

Fig. 6, Plate I., shows a tube sold by Messrs Watson & Son, of Holborn, for heavy-current work. The anti-cathode A is of solid copper plated with platinum, and supported on a hollow tube T.

Bianodal Tubes.—The type of tube known as

bianodal, an advance on the original focus pattern, is now almost universal.

The target which provides the source of the rays has been consistently named the anti-cathode and not the anode, because its chief function is to receive

FIG. 5.—Platinum anti-cathode of a bianodal tube which has been fused and perforated by the excessive discharge from a coil actuated by a Wehnelt break. The disc behind is the auxiliary anode, and the markings to the left are the light-reflections on the bulb.

the cathode stream and convert its energy into Röntgen rays, this function being fulfilled regardless of the position of the anode. In Jackson's focus tube and in most other X-ray tubes the anti-cathode is also the anode, but if an independent anode were provided, the anti-cathode being entirely disconnected, the cathode rays would still proceed from the alu-

minium cup, strike the anti-cathode, and generate Röntgen rays at their point of impact. Now if the hitherto independent anode be connected externally to the anti-cathode, the latter again becomes an anode, but the tube becomes bianodal and allows the passage of heavier discharges. Its value, however, seems chiefly to consist in a steadying effect and a reduction of sputtering where the anti-cathode is of platinum; the aluminium used for the supplementary anode is a far less troublesome material in this respect.

The tube may sometimes be slightly softened by disconnecting the auxiliary anode, and it is stated that the same result can occasionally be attained by disconnecting the anti-cathode and sending, for a short time, a reversed *and greatly reduced* current by way of the two aluminium electrodes.

Reversal of current in an ordinary focus tube causes particles of platinum to be thrown off from the anti-cathode and deposited on the bulb. This occurs to some extent when the main discharge is in the right direction, and eventually causes a purple coloration of the glass.

The auxiliary anode, generally a simple aluminium disc, is usually placed behind, and to one side of the anti-cathode. A typical bianodal tube is shown in fig. 7, Plate I., where *a* is the auxiliary anode.

Fig. 8, Plate I., shows Watson's penetrator tube, in which the anti-cathode A is slightly concave towards the cathode K, and between the two is an aluminium ring *a* attached to the anti-cathode. The ring and

anti-cathode are both anodal, but the ring is the working anode, an arrangement which increased the penetrative power of the rays without disturbing the focus of the cathode stream.

The Bulb.—Ordinarily the bulb is of soda-glass, lead-glass being highly opaque to Röntgen rays.

A tube designed for the treatment of skin diseases is illustrated in fig. 9, Plate I. The tube is of lead-glass excepting the soda-glass window W, which enables the operator to apply the rays to the affected area without danger to other parts.

The glass most commonly used fluoresces a brilliant apple-green in the path of the rays, and this colour being very similar to the fluorescent luminosity of a barium-platino-cyanide screen, considerable loss of effect may result unless the screen is placed in a light-proof box or camera with eyeholes, or the tube enclosed in blackened paper or thin cardboard.

Attempts have been made to meet this difficulty by making bulbs of material which emits different fluorescent colour from that excited in the screen. Lead-glass shows a beautiful blue colour, but is somewhat opaque to X-rays.

Lithium-glass gives a grey-blue light which affords considerable improvement. A glass containing didymium has been tried and gives red fluorescence, and as this is nearly complementary to the yellowy green excited in the screen, the luminescence of the latter is not nullified by that of the tube.

Within limits, a large bulb is superior to a small

one for heavy currents, and is less liable to change of vacuum.

Occlusion.—This term is applied to a curious absorption of gases by certain materials, and does not involve chemical combination in any ordinary sense.

Hydrogen is the most readily occluded of the gases, and palladium can accumulate considerable quantities in its intermolecular spaces. During the exhaustion of X-ray tubes a heavy Wehnelt discharge is periodically employed to free the electrodes of most of the occluded gas.

Mr H. S. Callendar made experiments which prove that the hydrogen occluded in the cathode acts as a carrier of the discharges from the metal to the air. With sufficient occluded hydrogen there is little or no sputtering of the aluminium, and in the absence of hydrogen, particles of the metal become the carriers and excite fluorescence and generate rays wherever they impinge. The residual occluded gas in most cases consists of hydrogen or water-vapour.

The Vacuum.—The operation and qualities of a tube *of given type and dimensions* are regulated almost entirely by the degree of vacuum in the bulb and the working temperature.

As has already been explained, excessively high vacuum almost amounts to insulation, and results in the passage of sparks over the exterior of the bulb, while low vacuum is associated with low resistance.

Between these extremes lie the degrees of " hard-

ness" of an X-ray tube, and accordingly the simplest method of estimating its condition is to ascertain what is called the alternative spark-length.

Alternative Spark.—The tube is connected in parallel with a point-to-point spark-gap, the ordinary spark-rods provided on the pillars of induction coils being generally quite good enough for the purpose.

With the discharge-points widely separated the coil is adjusted to deliver a current somewhat in excess of what is required for the tube, and while the coil is at work the points are gradually approximated until a spark passes between them every now and then.

The point-to-point distance at which this occurs is known as the alternative spark-length, and its value is a useful guide to the hardness of the tube.

Hardening and its Cure.—The one serious trouble is that continued use raises the vacuum and hardens the tube. The occlusion of the residual gases by the electrodes may partially account for this effect, though it is now known that most of the absorption occurs in the wall of the bulb, the gas being actually driven into the inner surface of the glass, with which it combines.

The colouring or "blackening" of the bulb is due to complex causes, which include the deposition on the inner surface of a certain amount of finely divided metal, and there is no doubt that this causes occlusion and increases the hardening tendency.

Such hardening being unavoidable, attention may be turned to its cure in ordinary tubes, and to the

design of those provided with special softening devices. A partial cure for hardness is prolonged and careful heating, and before the introduction of adjustable tubes it was common to nurse the tubes regularly after use, in hot ovens; but the resultant softening must be carefully distinguished from the temporary softening dealt with on p. 70. Sometimes a tube gives bad results capriciously, but recovers if put by for a day or two.

Occasionally it is possible to lower the vacuum slightly by the passage of a temporary discharge in excess of the normal value, thus expelling occluded gas from the heated electrodes.

Another method is to stick round the neck of the tube near the cathode a collar of tinfoil ½ in. wide having a tinfoil lug which connects it with the terminal of the cathode; the tube often recovers after a few seconds of use, and the collar is then removed. A third expedient is the reduction of the cubic capacity of the tube by heating one part of it until the atmospheric pressure flattens or indents the glass, but this requires extreme caution, as excessive heating will result in perforation.

If, after such treatment, a tube still remains too hard, re-exhaustion is the only remedy.

All such expedients are far from satisfactory, and it is better to purchase an adjustable tube at the commencement.

Fig. 10, Plate I., shows one of the earliest provisions for varying the vacuum of a tube. B, a bulbous annex to the tube, contains a small quantity

of caustic potash or other substance capable of absorbing traces of moisture, portions of which can be driven forth by the application of gentle heat. On cooling, the moisture is slowly re-absorbed. This method must be employed with caution, as it is easy to drive out too much, and troublesome to regain the correct degree of hardness.

The tube illustrated is of the double-cathode type formerly used for high-frequency work.

Mr Hillier originated tubes in which the vacuum is lowered by a discharge between aluminium wires arranged as shown in the treatment tube, fig. 9, Plate I. These tubes are made by Messrs A. C. Cossor & Co. of Clerkenwell Road, E.C.

Another method employed in many tubes is illustrated in fig. 6, Plate I.

The small annex shown contains a short length of palladium wire P to which heat is applied conductively through the projecting wire, and liberates the occluded gas as required. The glass tube and cork TC provide mechanical protection.

In another form (fig. 11, Plate I.), the palladium P is between two mica discs, the vacuum being lowered by approaching the wire W towards the wire W_1, and thus diverting a small portion of the discharge through P until enough gas is freed. By careful adjustment of the spark-gap between W and W_1 the arrangement becomes automatic, as a rise in vacuum diverts a portion of the discharge and a spark passes, liberating a small quantity of gas.

Yet another device of some promise involves the actual admission of outside air through a specially constructed mercury valve.

Many other methods have been tried or are in use, but those adopted by the best makers are so sure to afford good results that there is little need to extend the present account of them.

Hardening a Tube.—A bulb which has accidentally become too soft may be hardened by prolonged running with excessive current, which may sometimes be advantageously sent in the wrong direction, from cathode to anode, with the anti-cathode disconnected.

An ordinary bianodal tube is the survivor among all the complicated and interesting types introduced at various times, and may be all that is ever required by many an amateur; but in constant working the vacuum difficulty is very real, and regulating arrangements which save time, money, and worry become essential.

The Choice of a Tube.—The foregoing hints, which should enable the reader to use judgment in the selection of an X-ray tube, may here be summarised.

The tube should have substantial and firm supports for the electrodes, and metal caps with eyes for making connection.

In constructional detail, however, makers of repute leave little room for choice, and the selection of the *type* of tube is chiefly governed by the purchaser's resources.

For instance, the possessor of an expensive and

powerful coil will be wasting his money if he buys a tube which does not allow the output to exceed what would be obtained easily from a much smaller coil; and on the other hand it would be absurd to buy a tube with a water-cooled "target" for use with a coil giving a 3-in. spark.

A device for regulating the vacuum is, however, always likely to be valuable, and is well worth considerable additional expenditure.

If possible, the tube should be tested to ascertain whether the shadows thrown on the fluorescent screen or photographic plate have reasonably sharp edges when the bulb is at 6 or 8 inches distance from the hand; and though here there should be no fear of disappointment with good makers, the amateur should not take a second-hand tube on trust, if he can avoid it.

For very simple experimental work an alternative spark of 2½ or 3 inches is usual.

Such a tube will throw a visible shadow of the hand-bones on a fluoroscope when used with a coil only 1-in. spark, but for such small coils an even lower vacuum may be preferable. A 2½-in. or 3-in. alternative spark tube works well with coils up to 10-in. spark, but the larger coils give heavier discharges through a spark-gap or tube of given resistances, and consequently the *quantity* of radiation is increased.

An excessively hard tube tends to give flat negatives lacking contrast, as the bones are almost as transparent as the flesh to the highly penetrative

rays; but a reasonably hard tube gives structural details which can never be obtained with a soft tube, *provided that the time of exposure is correct.*

The exposure required is less than with a soft tube, and thicker parts of the body can be examined; but the decreased latitude makes it necessary to estimate it far more accurately.

For this and other reasons which have appeared the amateur is advised to commence work with a soft tube, which will provide good radiographs of shells, small animals, objects in boxes, and the human hand.

Also, it should be remembered that the penetrative power of modern tubes can generally be increased by raising the current value. Tubes are generally proportionately harder for work on the knee, the shoulder, the thicker parts of the body, and lastly, the head, which is the most opaque part of the human frame even in a normally intelligent person. A fairly hard tube is also advantageous for screen-work.

A tube too hard for a given purpose will do good work when it has been "warmed down" (see p. 70).

Doctors who constantly use X-rays commonly buy tubes of 2 or 3 in. alternative spark, and, as they harden, set them aside for cases requiring greater penetrating power.

The frequency of discharge seems to affect the working of a tube, and powerful discharges, even if they are not very frequent, are found best for radiography. High discharge-frequency is important for

fluorescent screen-work, as otherwise there is a flicker resembling that of a bad cinematograph, and the long intervals between the flashes considerably reduce the general brightness.

For such work a rapid succession of smaller discharges is often preferable. The maximum photographic effect is not necessarily concurrent with the best illumination of the screen, and, if possible, a new tube should be tested by both methods, preferably with the purchaser's own apparatus, as tubes sometimes show curious differences in behaviour when excited by various sources of supply.

New tubes generally harden after a little use, and then become fairly constant and reliable for a considerable time if carefully treated.

They should be "nursed" carefully at first, and the current should be kept moderate until they have settled down to fairly normal working.

Temporary Effect of Heat on X-Ray Tubes.—The experiments of Mr J. C. Porter, of Eton, show that there is a particular temperature at which the production of X-rays is at its maximum with a given tube, and that above or below this temperature the quality, as well as the quantity, of the radiation is altered. In one case the point of maximum illumination was 12° C. or 54° F., and the tube refused to work at all when cooled to the temperature of solid carbon dioxide. In a further experiment half of a plate was exposed for a hand radiograph, the temperature being 15° and the exposure 1 minute; the tube was then heated for ¾ minute and the second

half of the plate exposed for $6\frac{1}{2}$ minutes. Though the first half had less than $\frac{1}{6}$ of the exposure given for the second half, the image of the bones was clearly visible, whereas in the long-exposed portion, only the faintest trace of bone-shadow was distinguishable, the rays having barely penetrated the flesh; yet the blackness of the film surrounding the hand-shadow showed that the "quantity" of radiation had been great.

The effect of heat, therefore, is to soften the tube *temporarily*, causing it to emit weakly penetrative rays, and a tube which is useful for radiographs of the abdomen, skull, or other thick parts can thus be softened sufficiently to give good radiographs of comparatively transparent objects. A common method is to heat the tube over a spirit-lamp until the required degree of softness has been attained, adjusting the discharge-rods of the coil just beyond the sparking limit and then commencing the exposure; if, during its progress, the resistance rises, sparks begin to pass, warning the operator that a little more heat is required.

If general heating has been applied prior to the commencement of the exposure, the additional warmth is best applied to the annex immediately surrounding the cathode.

The heat may be applied during exposure if an insulated spirit-lamp is used, but neither the spirit-lamp nor the operator's hand should be interposed between the tube and the object.

The softening should be done very carefully and

rather gradually, a waving motion being given to the lamp, as otherwise the bulb is likely to crack.

The container of the lamp should be of glass, and a simple insulating handle is easily made from ebonite or hard wood. Its fastening must, of course, be firm, for the person being radiographed (especially for an injury) may show marked displeasure if a heavy burning spirit-lamp be dropped on the damaged member.

The condition of a heated tube may sometimes be maintained by using a current strength sufficient to keep the anti-cathode red-hot.

CHAPTER V

PRACTICAL X-RAY WORK

Accessory Apparatus.—Some simple appliance is necessary for holding the tube in any position required for use.

The ideal tube-holder should have:—

1. Universal movement.
2. Rigidity.
3. Lightness as far as is compatible with 2.
4. Insulation.

Rigidity is essential in radiography, though for screen work it matters little so long as the requirements of safety are fulfilled.

Lightness is important in portable apparatus. Hard wood has adequate insulating properties; in fact, the wooden retort-stands sold for chemical and physical use are excellent for ordinary X-ray work if their bases are weighted or otherwise made sufficiently stable.

Spark-gaps.—A pair of spark-gaps for connection in series with tube and source of supply are generally useful in Wimshurst work, even with large machines,

and sometimes they improve the working with induction coils when there is any tendency to reverse currents.

In fig. 6, A is a board 7 in. × 4 in. × ½ in. C D are upright rods of ⅜-in. ebonite, 4 in. in clear height above the board, and fastened thereto by shouldering them and forcing them into tightly fitting holes served with glue.

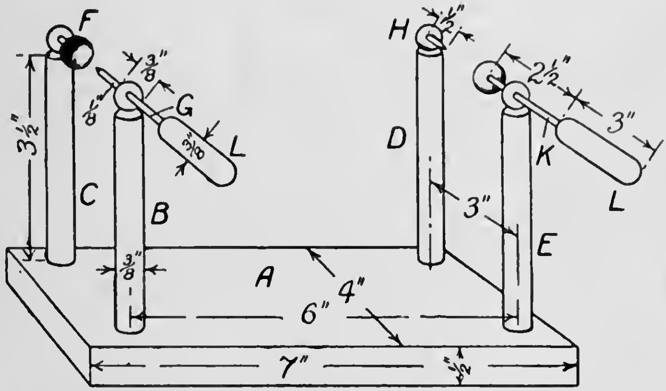


FIG. 6.—Spark-gap apparatus for use with a Wimshurst machine.

The top of each pillar is drilled and tapped to take the threaded shank of a spherical head.

The heads are drilled at right angles, their shanks F and H being provided with fixed sparking electrodes screwed into the holes. The electrode F is in the form of a hemispherical cup 1½ in. in diameter, with the concavity towards the pointed electrode G.

Into the side of the ball F (previously drilled) a ½-in. length of ⅛-in. brass rod is soldered.

A second small hole for the insertion of the wire from the Wimshurst may also be drilled in a direction at right angles to that of the rod.

The pillars B and E are similarly made and mounted, excepting that the brass rods G and K are free to slide in the holes. Each rod is $2\frac{1}{2}$ in. long and carries an ebonite handle L. The rod K carries a concave electrode similar to F.

In use the point electrode H is connected to the positive terminal of the coil or machine, and the cup electrode F to the negative, the tube being connected across G and K.

Light-tight Plate Bags.—It is obvious that the photographic plates must be screened from the action of ordinary light by some material as transparent as possible to X-rays.

Envelopes of black paper may be made, but "Tylar's light-tight bags" are cheap and easily procurable.

The plate is inserted in the smaller envelope *with the film side immediately beneath that part of it which has no folds*, and the flap is turned over, the smaller envelope being inserted in the larger, *flap foremost*, with the film side again immediately under the unfolded part of the paper. The outer flap having been turned over, the plate is ready for a radiograph.

It is advisable to use plates specially prepared for X-ray work, and these are generally put into separate envelopes by the makers before being packed in boxes. Hence it is only necessary to take the

radiograph and then remove the paper in a dark room before development.

Metal Boxes.—A stout metal box should be at hand for the protection of all X-ray or other photographic plates, dark-slides, and hand cameras containing films. In a house containing an old-fashioned photographer who still adheres to the obsolete "sun pictures" obtained with the camera, neglect of this precaution may result in some difference of opinion regarding the relative personal qualities of the photographer and the radiographer.

Photographic Apparatus.—For developing-dishes, measures, printing frames, etc., the ordinary stock of a photographer, the inexperienced reader must refer to suitable text-books.

Fluoroscopes.—Detailed descriptions of the preparation of fluorescent screens would be out of place here, as amateur attempts in this direction generally entail much waste of time and an expenditure of money which would purchase two or three good screens of the same size as those spoilt.

The following is an outline of a simple method of procedure for those who desire to experiment.

The fluorescent substance, barium platino-cyanide, a bright yellow salt which must have been specially prepared for the purpose, is extremely costly. The support is of fairly stout, strong white cardboard. This is covered over uniformly with rather thick gumwater, or, preferably, with celluloid dissolved in amyl acetate, and the platino-cyanide is dusted evenly over the surface from a sieve of fine muslin.

It is well to practise the process several times with common salt, as the coating *must* be uniform, and failure involves waste of material.

The superfluous crystals having been shaken off and preserved, the screen is mounted in a suitable wooden frame.

The coated surface must be carefully protected, a thin celluloid covering fastened on the frame at about $\frac{1}{4}$ in. from the screen being a common arrangement.

Plate-glass, though more breakable, has the great advantage over celluloid that it protects the eyes from the rays, especially the more dangerous but less penetrative kinds. The glass or celluloid should never be rubbed too vigorously, as it is not uncommon for the electrical charge thus generated on its surface to attract loose particles of the salt away from the screen.

A simple screen of this type can only be used in a darkened room, and its effect is even then impoverished by the light from the fluorescent bulb.

It is found, however, that nothing equals a suitably darkened room for serious work, and it is easy to screen the bulb sufficiently to exclude its fluorescent luminosity.

Fluoroscopes fitted with light-tight boxes or hoods having holes for the eyes were much used in the early days of X-ray work, but have found little favour, because it takes a considerable time for the eye to accommodate itself to the darkened interior of

the fluoroscope after being strongly excited by daylight or artificial sources.

The amateur who finds difficulty in arranging a suitably darkened room may make a box provided with two single eye-pieces edged with thick plush, or with a single large eye-piece to fit the forehead, as in some patterns of the common stereoscope.

The screen and eye-piece are fixed at opposite ends of the box, so that no extraneous light can fall upon the former; this enables the user to examine the fluorescence on the screen regardless of the general illumination in the room.

The distance between the eye-piece and the screen may be about a foot.

An alternative arrangement is a collapsible camera with the screen in place of the usual dark-slide and the eye-piece in place of the lens front. Old cameras can often be obtained at very low cost, and are easily adapted by the substitution of hinged links or stays for their heavier supporting members. Bellows alone are also obtainable at low cost, and are easily fitted to light frames and supports.

Fatigue of Fluoroscopes.—After prolonged use the barium platino-cyanide suffers from molecular fatigue and the loss of its water of crystallisation; its efficiency is thereby considerably impaired, the yellow salt becoming brown.

P. Villard says that a screen can be restored by exposure to sunlight, and that the beneficial effects result chiefly from the action of rays below the green in the spectrum, violet and ultra-violet light

having but little effect. If the trouble proves irremediable the makers will generally allow 15 or 20 per cent. of the cost in the purchase of a new screen.

Varnishing the screen has been recommended as a preventive of dehydration of the salt.

Intensifying Screens.—One of the earliest materials employed for fluoroscopes was crystalline calcium tungstate, a mineral which fluoresces with a pale blue light.

To the eye the fluorescence is greatly inferior to that of barium platino-cyanide, but the light emitted is far more chemically actinic, and the value of the material for intensifying the effect on photographic plates was soon recognised.

The method employed is to lay upon the film of the plate a thin screen covered with the salt, the coated side being towards the film.

Much of the radiant energy which would otherwise pass on through the film, only to be absorbed wastefully in the glass behind and in objects beyond, is arrested by the screen before it reaches the film and is converted into ordinary luminous energy, which acts photographically and adds its effect to that of the X-rays themselves. The difficulty in making an intensifying screen is to obtain a coating so thin, even, and finely divided that the blurring and grain are both insufficent to impair the sharpness of the results.

Great improvements have been effected in these directions, and washable screens can now be obtained,

which shorten exposures by 75 per cent., giving sharp, even, and clear results.

Calcium tungstate is cheap as compared with platinum salts, and the amateur can therefore experiment far more freely with it. Should it prove difficult to make a satisfactory practical intensifying screen, he will nevertheless find it interesting to employ a piece half the size of a given X-ray plate, taking a radiograph with normal exposure and observing on development the difference between the two halves in the result.

The method of coating is the same as for barium platino-cyanide.

Reverse Currents and their Prevention.—The ordinary spark-coil is apt to give some trouble through reverse currents, which occur at make or as a result of oscillations in the "break" discharge. These currents are very damaging to the X-ray tube, and it is necessary to eliminate them if possible.

The introduction of a spark-gap having a point opposed to an electrode of larger area facilitates the passage of a discharge leaving the point, and accordingly if the point-electrode is connected to the positive terminal of the source of supply, it tends to cut off any discharge which would otherwise take place in the opposite direction.

Mr Duddell found that a high degree of so-called rectification can be attained if the larger electrode is concave towards the point. A spark-gap "rectifier," or, more properly, valve, is described on p. 73.

Another valuable valve consists of a mica disc

mounted on the shaft of the mercury interrupter so as to revolve between one or more pairs of spark-electrodes. The disc is pierced with holes, and no discharge can pass between the electrodes unless they coincide with the holes. Matters are so adjusted that mica is interposed at all moments except that of the main useful impulse.

Special auxiliary vacuum tubes, with large spiral cathodes and small anodes, are used to attain the same result, one of the commonest, due to Sir Oliver Lodge, being very constant and reliable.

Other forms may require softening devices similar to those fitted to ordinary tubes. Like X-ray tubes, these valves are beyond the constructional resources of the average amateur.

Radiometers and Pastilles.—A useful and interesting instrument for rough tests of the hardness and penetration is Benoist's radiometer or penetrometer. An annular ring of aluminium is divided into sectors, the thickness of which is such as to form steps between two extremes.

The centre of the annular space is occupied by a thin sheet of silver, and the comparative penetrating power of rays is measured by interposing the instrument between the tube and a fluoroscope and noting which step gives a shadow about equal to that cast by the silver.

It is a curious fact, which cannot be explained here, that for a given strength or "quantity" of radiation the opacity of silver is nearly equal for rays of widely different hardness, and consequently

it provides a standard with which the thicknesses of aluminium can be compared.

Another form due to Dr Wehnelt has an aluminium wedge arranged to move longitudinally past a slit which is partly covered by a fixed silver plate of definite thickness; when the correct thickness of aluminium lies over the slit the shadows cast by the two parts of the slit appear equally dark, and the division between them disappears, the adjustment of the wedge being indicated by a scale. Other radiometers are constructed on somewhat the same principles as Wynne's photographic print meter, but that the intensity of illumination is noted on a fluorescent screen instead of being printed on a strip of sensitised paper.

Such arrangements must be inferior to the Benoist instrument, as they do not differentiate between intensity and penetrative quality of radiation.

For measuring therapeutic (medical) doses of X-ray treatment, Sabouraud's pastilles are employed. These are of compressed barium platino-cyanide, and on exposure to the rays change their colour from green to pale yellow, and finally to deep orange, being matched at various stages with standard tints.

Milliampèremeters.—These are valuable for the measurement of the current through the tube; the largest water-cooled tubes seldom take more than 9 or 10 milliampères even during short exposures, but in ordinary work a current of only 3 or 4 milliampères is heavy.

Protective Apparatus.—In cases where powerful rays are employed or prolonged experiments carried out the operator should be adequately protected against X-ray "burns," and it should be remembered that a common case of special risk is an exhibition of X-ray experiments at a bazaar or similar gathering; the spectators have nothing to fear except from powerful apparatus, but the exhibitor is exposed for long periods.

Considerable protection is afforded by stout leather gloves with wrists long enough to be covered by the coat sleeve.

Lead-glass spectacles may be worn, and plate-glass may be used to cover the fluoroscope, as described on p. 76.

The softer rays are the more dangerous, and as the amateur's tube is commonly soft, especially when new, the danger may be greater than the magnitude of the apparatus would at first sight suggest; on the other hand, the leather gloves cut off the softest rays with comparative ease. When the work is solely radiographic the tube may be so shielded that all rays except those required are cut off, the operator arranging the plate and object so that no part of his body is exposed to radiation.

On the whole, the amateur is advised to wear leather gloves whenever he works for more than two or three minutes, to avoid all needless exposure or proximity to the apparatus, and to increase all safeguards in proportion to the power of his apparatus and the period of working. Above all, let him take

instant and thorough steps on the first certain indication of trouble.

Dealers in X-ray apparatus supply special shields for tubes and also lead-rubber gloves, aprons and masks, and lead-glass spectacles.

Such appliances should be used by all who are seriously engaged in the work.

An X-ray operator in his "Sunday-best" is an awe-inspiring object faintly suggestive of an armoured gentleman of the twelfth century.

Arrangements and Connections.—It is scarcely necessary to explain that ampèremeters, when employed, are connected in series with the coil and the source of supply, while voltmeters are connected directly to the primary terminals of the coil (see diagram, fig. 7).

A mercury interrupter is connected with the spring and pillar of the contact breaker, unless the coil is provided with special terminals or a separate condenser, but in all cases the resulting connections should put the interrupter in series with the source of supply and the primary winding, the condenser being connected across the terminals of the interrupter. The contacts are screwed apart and the hammer wedged to prevent chattering.

No condenser is used when the interrupter is of the Wehnelt type.

If a Wimshurst be used, the two spark-gaps (see p. 84) are connected in series with the tube, one on either side (see fig. 7, D).

It has often been said that radiographs produced

by influence machines are clearer than those obtained with coils, but it is found that this is due to the disturbing effect upon the cathode stream of the magnetic field from the coil. It is therefore im-

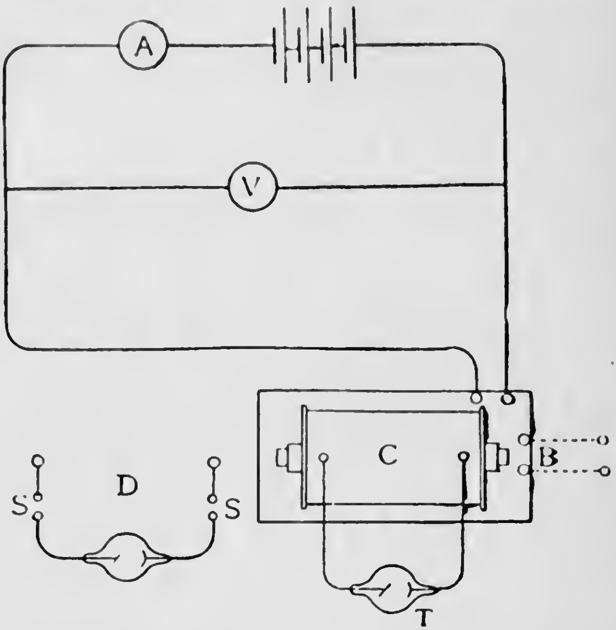


FIG. 7.—Showing diagrams of connections for an induction coil and (D) for a Wimshurst.

C. Coil. V. Voltmeter.
B. Break. T. Tube.
A. Ammeter. S. S. Spark gaps.

portant to keep the tube at a considerable distance from the coil: Mr Miller recommends 7 feet. All wires leading to the tube should be firmly secured from falling off, and the distance which should separate coil and tube clearly necessitates the use of wire heavily insulated or hung on proper supports.

The wires must clear the walls of the tube, and no adjustments should be attempted in the secondary circuit while the primary current is flowing.

Where there is a choice of tubes, the harder should be employed for such subjects as the thorax, head, etc., but the beginner's first subject should be a friend's hand, preferably the slender hand of a lady, though many of the gentler sex raise objections like one of Dickens' heroines :—" I do not wish to regard myself, nor yet to be regarded, in that bony light."

The tube having been firmly secured in position, a small current is *momentarily* turned on, and the appearance noted.

The bulb should appear obliquely divided in two halves, that opposite to the anti-cathode being uniformly luminescent with apple-green or canary-green light, the other being nearly dark. The dividing plane should be coincident with that of the anti-cathode.

Wrong direction of current is indicated by the alternative appearance of curious patches and markings, notably a fluorescent patch opposite to the anti-cathode, and suggesting a magnified image of it. This patch is caused by the cathode stream from the surface of the anti-cathode (now a cathode) striking the glass, and when, as in early tubes, the platinum plate is held by a pair of copper rivets visible on its working face, these are sometimes reproduced as curious magnified dark patches on the bulb. The experimenter's interest in these pheno-

mena must not lead him to prolong his observations for more than a second or two, as considerable damage may ensue.

With bianodal tubes there is more confusion in the shapes of the dark and luminous patches obtained on reversal, as the anti-cathode and the supplementary anode both become cathodes emitting independent cathodal streams.

The club-shaped projections and whispy streaks of darkness on light-green fluorescent ground which sometimes appear in the tube under normal conditions are due to local negative charges which affect the cathode stream or themselves set up subsidiary rays.

All being in adjustment, the current may be increased gradually to full value, but the maximum current should never be turned on at once.

The screen may be placed about 10 in. from the bulb, with the coated side towards the eyes, the hand being placed against the back. The shadows of the bones should be plainly visible, and with a good tube they should exhibit considerable structural detail.

The leg, arm, and foot (the last-named in a boot) provide interesting subjects in addition to those named below.

The best effect is obtained when the object to be observed is as close to the screen as possible; the hand, for instance, should be flat against it.

Precautions.—For X-ray dermatitis and its prevention see pp. 42-44.

Interesting Subjects.—Numerous interesting subjects for screen and plate will occur to the ingenious experimenter, but a short list may prove useful:—

Coins in a purse, mathematical instruments in a case, box fastened with nails, plug-resistance box, fountain pen, objects in aluminium cigar-case, and a key held in clenched fist.

The corpses of small vertebrates also make beautiful radiographs and provide comparatively easy tasks for a low tube and a small coil.

A live cat or dog in a basket is a good subject for fluoroscopy, and the movements of a cat's jaw when it mews and of the vertebræ in the tail are fascinating to watch.

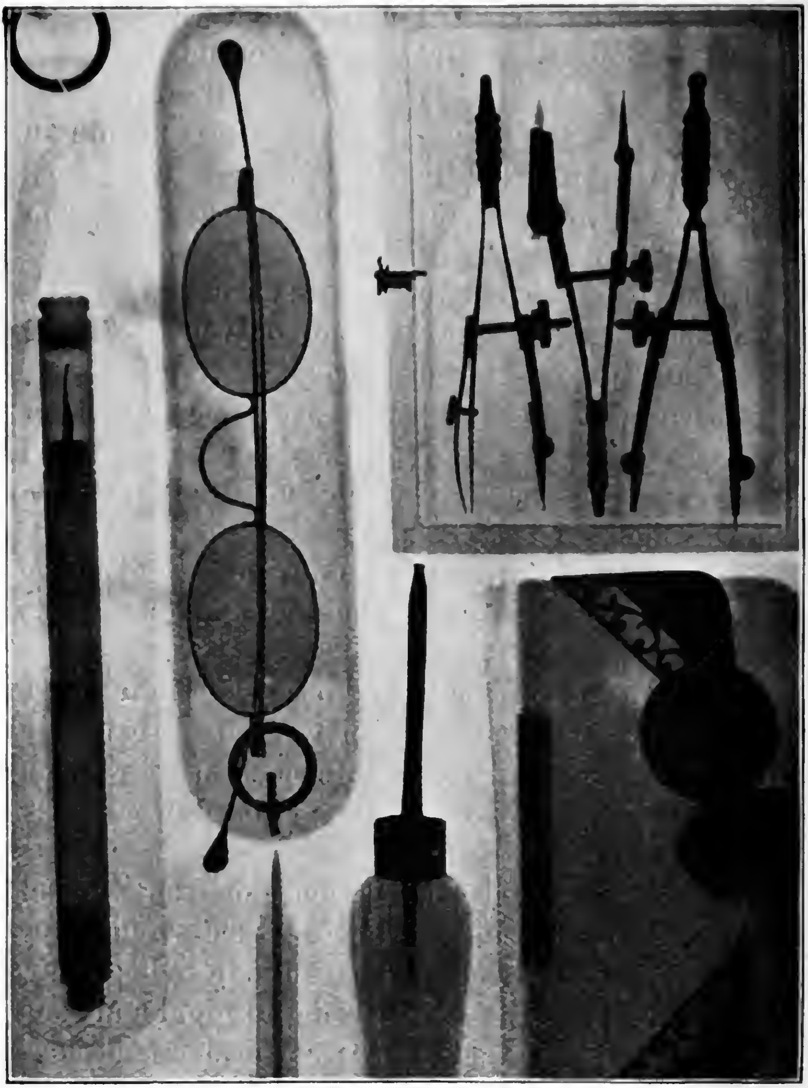
A curious and interesting subject for a radiograph is a human hand in which the lines and depressions are made visible.

For this purpose putty is kneaded well into the skin, and the surface is then worked up carefully with glycerine until it is quite smooth, after which a little subnitrate of glycerine is rubbed over gently and smoothly.

Radiography.—The adjustment of the current and speed of interruption which best suits radioscopy does not always give the best results in radiography, the tendency on the whole being to rapid and comparatively weak impulses for the former and slow-frequency strong impulses for the latter.

If no screen is available, the working of the tube must be judged by the degree of fluorescence in the glass.

PLATE II.



MISCELLANEOUS GROUP OF OBJECTS :—Fountain pen in case ; spectacles in case ; pencil, showing graphite ; bradawl, showing grain of wood ; instruments in wooden case ; leather purse containing coin, and showing internal and external clasps and ornamental metal corners of flap. Conditions as for Plates III. and IV., except exposure, which was 10 seconds.

When a Wimshurst is employed the only possible adjustments are length of spark, speed of plates, and angle of neutralising brushes.

In taking the first radiograph a useful additional appliance is a sheet of $\frac{1}{16}$-in. lead about 8 in. × 9 in. The wrapped-up plate, hitherto safely stowed away in the metal box, preferably at some distance, is now laid on the table with the film side uppermost.

The tube must not be set working when the plate is out of the protective box, until all is ready for the exposure.

The hand to be radiographed is laid flat on the plate with the tips of the fingers and thumb well within the margin.

The tube is placed horizontally with the centre of the anti-cathode vertically above the centre of the plate, the fluorescent portion of the bulb being between the anti-cathode and the plate.

The distance between the plate and the tube involves a compromise between two conflicting advantages. Excessive distance entails needlessly long exposure, but gives fine definition and a minimum of distortion; these advantages are sacrificed if the distance and exposure are abnormally shortened. Distortion in this case is due to the fact that the rays start from a point and proceed in straight, radial lines. The shadows which they cast are therefore similar to those thrown by a point of ordinary light. If the distance between the object and the source be great, the angle subtended by the object is small and the direction-lines of the radiation are

nearly parallel, the shadow of the object being but very little larger than the object itself.

If, however, the object and the screen or plate be brought near to the source, the subtended angle and the divergence are great, and the shadows are consequently considerably magnified.

The under surface of the object, where it is in contact with the wrapping of the plate, does not suffer this magnification, but portions further removed from the plate become magnified according to the distance; it follows that thick bodies suffer far more distortion than do thin bodies.

Accordingly the best distance is determined by the nature of the subject and the particular qualities of the apparatus. For a hand it should be at least 6 in., but preferably 10 in. or 12 in., while 9 in. or 10 in. is a minimum for an arm or the lower part of a leg. For the thorax 18 in. or 20 in. will give fair results, but if the apparatus is powerful and accurate localisation is desired, this distance should be greater. 10 in. is a good standard distance for simple "small" work with a good coil.

Trial Exposure.—Let it be assumed, by way of example, that, from the data given below, the estimated exposure is about 1½ minutes. The current is turned on, the subject keeping his hand perfectly still, and at the expiration of ½ minute the discharge is stopped; about 1½ in. of the hand at the finger-end is now covered by the lead plate, another half minute of exposure being given. The plate is now moved so as to cover another 1½ in. and a third

PLATE III.

SUCCESSIVE TRIAL EXPOSURES from 10 to 40 seconds, 9″ spark coil. Cossor's Bianodal Tube warmed down to $3\frac{1}{2}$″ alternative spark. Edward's Cathodal Plate (whole-plate size). Distance between tube and plate 12″. Metol Quinol Developer applied for 20 minutes as described in text.

half-minute is given, and so on until there is only one small strip left uncovered. If the lead plate so used causes inconvenience, it may be made to rest on suitable blocks so placed that it bridges the hand without touching it.

When exposures are long or injury has made the subject shaky, or when successive exposures are required, as in stereoscopic work, sand-bags are often valuable for preventing movement.

The emulsion of the plate is now divided into differently exposed strips whose time values are $\frac{1}{2}$, 1, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, and 3 minutes. See Plate III.

If there is much doubt as to the approximate exposure, the difference between the successive exposures may be increased, but in all cases time-records must be kept.

It is necessary to remember that as the bulk of the rays practically emanates from a *point* source on the anti-cathode, their intensity is inversely proportional to the square of the distance from that source. For example, if an exposure of 3 minutes is required at a distance of 6 in., the exposure necessary, when the distance is increased to 12 in., is not 6 minutes (3×2) but 3×2^2, that is 12 minutes. The following figures give extremely rough indication of the exposures required for different objects, using a 1-in. spark coil—presumably with hammer interrupter:—Hand, 20 minutes; coins in purse, 10 minutes; foot, 30 minutes.

Even with so small a coil, however, modern tubes would probably give good results with shorter

exposures, and the range of possibilities may be realised when it is pointed out that apparatus now available will give an instantaneous radiograph of the abdomen of an adult as a result of the single flash from one interruption. Moreover, the tube may be put so far away from the body that stones in the kidney, etc., are shown without appreciable distortion of shape or confusion as to locality. While it is clearly impossible, therefore, to specify times, the individual worker can ascertain the best time, say for a hand, and then avail himself of the *comparative* values indicated by some such scale as the following, which was published a few years ago by that maker of excellent coils, etc., Mr Leslie Miller. The actual figures given are the exposures in *seconds* for a 12-in. coil used with a good mercury break, taking about 3 ampères from supply mains at 200 volts (or 4 ampères at 100 volts). Hand and wrist, 20; foot and ankle, 30; elbow and forearm, 45; knee, 60; chest, 120; shoulder or lower thigh, 150; thigh, abdomen, pelvis, or hip, 180; head, 210.

These figures have been improved by the introduction of better plates and tubes, but the *proportion* between them is unaltered. Correction must of course be made, as indicated on p. 92, if the distance between the tube and the plate is varied.

Glass lodged in the body is sometimes very difficult to detect, as its opacity is nearly equal to that of its surroundings.

Blood is comparatively opaque, and full-blooded or muscular people always need longer exposures than

those who are anaemic. Surgeons experience difficulty through the opacity of plaster or strapping, and of iodoform, even, when only in gauze.

The liver and stomach are very opaque, making the observation of small semi-transparent objects difficult, but the lungs are very transparent.

Dry Plates and their Development.—Any good make of rapid plates will afford radiographs, but plates made specially for the purpose and coated with extra thick emulsion are greatly superior.

The developer recommended by the makers of particular plates may be relied upon to give good results, and if the exposure has been correct the period of development should have a known value which the manufacturers should state. With Wratten's X-ray plates the author has obtained excellent results by 5 or 6 minutes' development in "Parakone," an excellent product sold by Messrs Hinton & Co. of Bedford Street, London, W.C.

Using the two-solution developer as sold for ordinary photographic work, one part of *each* solution in a total of four parts is the proportion recommended for radiographs of large opaque parts of the body, and about one part of each in a total of ten for the hand, shells, and similar small objects.

If necessary the temperature of the developer should be raised to 60° or 65° C. by standing the measuring glass in warm water and stirring.

After dusting the plate with a soft camel's-hair brush, develop as in ordinary photography. A valuable acid-fixing bath is made up by dissolving

PLATE IV.

RADIOGRAPH OF A HAND. Exposure 20 seconds in accordance with the results of the trials shown in Plate III., where the centre strip shows the best combination of contrast and detail. All conditions the same as for Plate III.

6 oz. of "hypo" and ¼ oz. of metabisulphite of potash in 1 pint of water

Final Exposure.—The strip of the plate which shows the best detail and contrast indicates the correct exposure, and an actual radiograph should be successful if the exposure, the developer, the temperature, and the condition of the tube remain unchanged.

To secure the latter the tube should be worked for a short time before making either of the two exposures.

In choosing between the strips it must be borne in mind that a longer exposure is required for the wrist and palm than for the finger-tips, and that a compromise must be made between them to get the best general effect.

Printing.—P.O.P. is almost invariably best for X-ray work, though, if a print be urgently required, it may be made on glossy bromide paper.

Radiographs may even be taken directly upon rapid bromide paper, several copies being obtained in one exposure if the necessary number of pieces is used. Such prints are paper negatives in which the flesh shows darker than the bones. The only merit in the process is a saving of time and of small expense.

For further details of photographic methods the reader must consult suitable text-books.

Stereoscopic Radiography.—Curious and useful results are obtained from a pair of radiographs of an object so taken as to produce an appearance of solidity when combined in a stereoscope. The

PLATE V.

PARTRIDGE, SHOWING FOOT BROKEN BY SHOT. The curious dark patch in the middle of the body is the gizzard. Exposure $1\frac{1}{2}$ minutes. Alternative spark 4″. Distance between tube and plate 18″. Other conditions as for Plates III. and IV.

method adopted is to move the tube in a direction parallel to the plane of the plate between two equal exposures taken on separate plates; the resulting negatives (or prints from them), when viewed in a stereoscope, do not exhibit the true stereoscopic effect which would be apparent to an observer placed with his eyes at the positions occupied successively by the anti-cathode of the tube, even assuming that the body observed were translucent and illuminated by ordinary light.

In stereoscopic radiography only shadows are combined, and the effect of solidity, though striking and often beautiful, is in a sense spurious.

The heart of a mammal having the veins carefully emptied of blood and injected with mercury makes a wonderful subject, and if powerful apparatus is available, parts of the human body viewed stereoscopically are most instructive, and of course in many cases of great medical and surgical value.

If serious work on these lines is to be attempted, an appliance must be prepared to enable the operator to insert and remove the two plates without the slightest movement of any part of the subject. For medical purposes elaborate and expensive apparatus is sold for this purpose, but a simple method for ordinary work is to provide a strong frame of thin wood over which vellum or very strong hard paper is stretched drum-tight.

The recessing of the frame into which, if it were used as a picture frame, the picture and glass would ordinarily drop, should be only deep enough to

accommodate with ease the X-ray plate in its envelope.

Before covering the frame one component end of it should be cut away to the same depth as the recessing, so that when the vellum is in place there is between it and the frame at this end a slot into which the plate can be introduced so that it lies immediately beneath the vellum. The dimensions should be such that when pushed home the plate projects slightly from the slot and can thus be easily removed after exposure.

If the vellum is slightly moistened, pulled over the frame, and held to it by small brads and a little glue, it will stretch tightly when dry. Means should be provided for weighting or securing the frame on the table to avoid all risk of movement during the insertion or changing of plates.

One of the plates having been inserted in the finished frame, the tube is fixed at a height of about 20 in. above the (previously marked) centre of the vellum.

This adjustment may be aided by the use of a small removable plumb-line attached beneath to a thread tied circumferentially round the bulb in a vertical plane.

The bulb is now moved about $1\frac{1}{4}$ in. to one side in a direction parallel to what will be the top or bottom edge of the radiograph when viewed in the stereoscope, and after the tube has been worked for a short time to get it into a constant condition, a plate is inserted in the frame film upwards, the object to

be radiographed is placed upon the vellum, and the necessary exposure is given.

Without disturbing the object, the plate is now taken out and the tube is moved until the anti-cathode is $1\frac{1}{4}$ in. on the other side of the vertical line from the centre of the vellum, that is, until it is $2\frac{1}{2}$ in from its former position.

All being adjusted, the second plate is inserted, an equal exposure is given, and the negatives are developed simultaneously in the same dish.

An arrangement for quickly moving the tube through the correct distance should be devised if extensive work is undertaken.

Stereoscopes.—If of suitable size, the negatives may be viewed in an instrument of the kind used for stereoscopic lantern-slides, or prints may be inserted in one of the common type.

In all cases great care must be taken to place the two views in perfect symmetry and in correct relationship. An interchange of position will soon reveal by an appearance of solidity or otherwise the correct disposition of the views, which should then be recorded by marks. The two views of shells given (Plates VI. and VII.) are too big for an ordinary stereoscope, but the reader who does not possess or cannot make a Wheatstone instrument may cut out the small shells from the two plates and mount them on cards at the right distance and position.

For such subjects as these shells the vellum frame is not required, and may be replaced by a piece of card to which the subjects are glued; the card is

hinged to the table by a strip of music-binding, so that the plates can be intruded under it or removed without causing any disturbance of position.

Wheatstone's Stereoscope.—The objects commonly radiographed are generally too large for the appliances used in ordinary photography, but a Wheatstone stereoscope provides means for combining

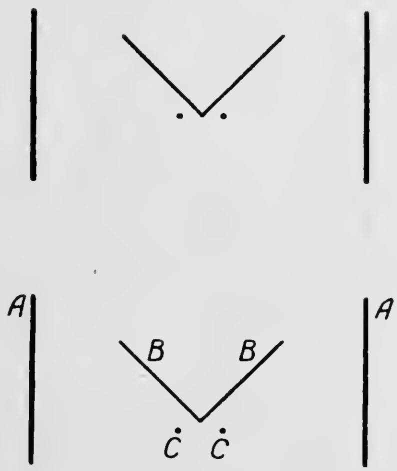


FIG. 8.

the images of negatives or prints of any reasonable size.

A very simple arrangement of two mirrors at right angles and a pair of drawing boards propped against books will act as a stereoscope for viewing larger prints, such, for instance, as those given, and the method employed is indicated in plan in fig. 8, where A A are the prints, B B the mirrors, and C C the eyes of the observer. It will be obvious that the prints must be equidistant from the mirrors and

exactly opposite to each other, and though the orbital and accommodating muscles of the eyes may bring the two views into unison when they are improperly adjusted, the strain is uncomfortable and probably injurious, and the stereoscopic effect is imperfect.

It is also of the utmost importance to use equally

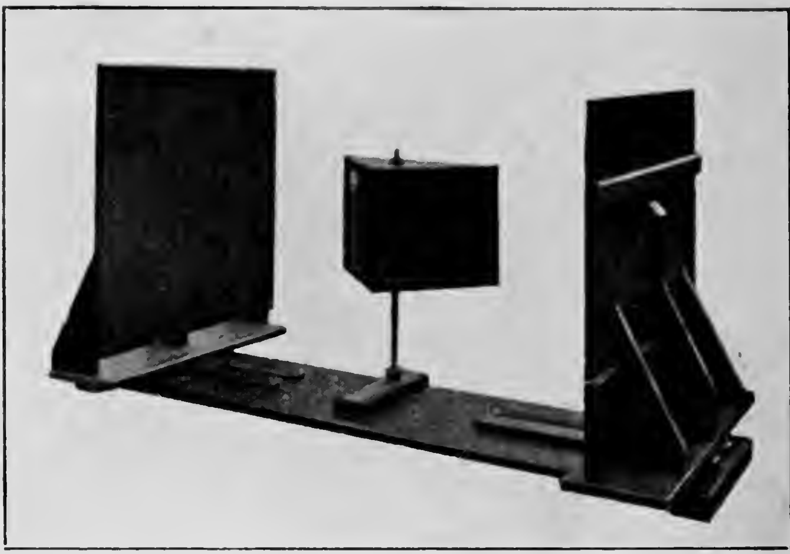


FIG. 9.

dark prints or equally dense negatives and to illuminate them equally in the stereoscope.

For satisfactory work a properly designed appliance on the lines indicated by figs. 9 and 10 may easily be constructed by the amateur. The wooden baseboard in this example is about 36 in. long, and upright end-boards 16 in. square are provided for the prints, which are secured to them by drawing

pins. These boards slide longitudinally, and one (see fig. 10) also vertically.

The pair of mirrors is arranged on the two right-angle faces of a wooden box shaped like a right-angled 45° prism mounted on a rod about which it can be turned stiffly.

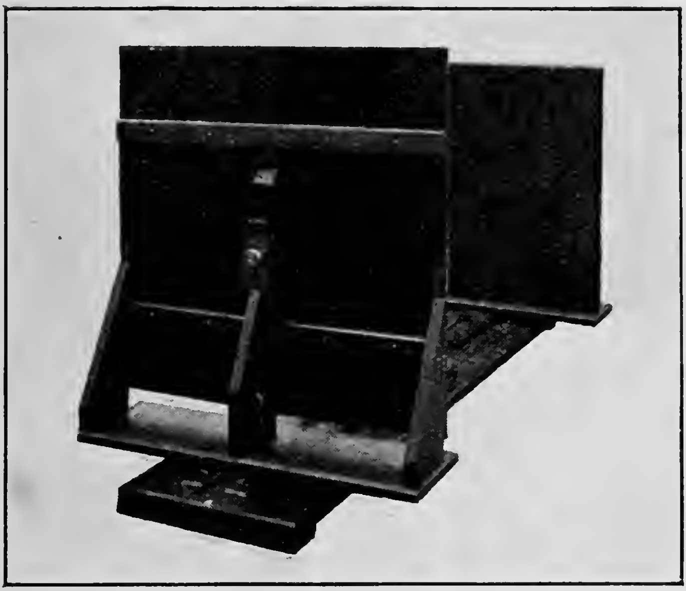


FIG. 10.

The rod rises from a foot which slides forward and backward in guides secured to the base-board and can be clamped thereto when the correct position has been found. Each mirror is about 6 in wide and 7 in. in height. All sliding arrangements should be strong and substantial, or endless trouble will be encountered.

In the amateur-made example shown the size

of the mirrors is 7 inches across and 6 inches in height.

Individuals sometimes experience considerable difficulty in seeing radiographs stereoscopically with this instrument, and such difficulty occasionally reveals unexpected inequality of vision between the two eyes.

The views of shells (Plates VI. and VII.) can be cut out and mounted in the finished stereoscope as a preliminary to stereoradiographic work by the experimenter himself; their effect is not quite so striking as those sometimes obtained, probably because the tube was placed rather high for such a subject in fear of stereoscopic exaggeration. For viewing negatives, boxes are substituted for end-boards, the sides facing the mirrors being of ground-glass; plate-carriers are fitted in front of the glass, and the boxes contain lamps of equal candle-power, which illuminate the ground-glass and the negatives from behind.

Stereoscopic Fluoroscopes.—Excellent stereoscopic screen effects are obtainable by the alternate excitation of two sources of X-rays at the correct distance apart.

A series of stereoscopic shadows is cast on the screen, but these yield only a blurred and indistinct appearance until some selective appliance confines the vision of each eye of the observer to the shadows produced by one source only. The necessary selection is obtained through revolving apparatus which cuts off the vision of the eyes alternately by the inter-

PLATE VI

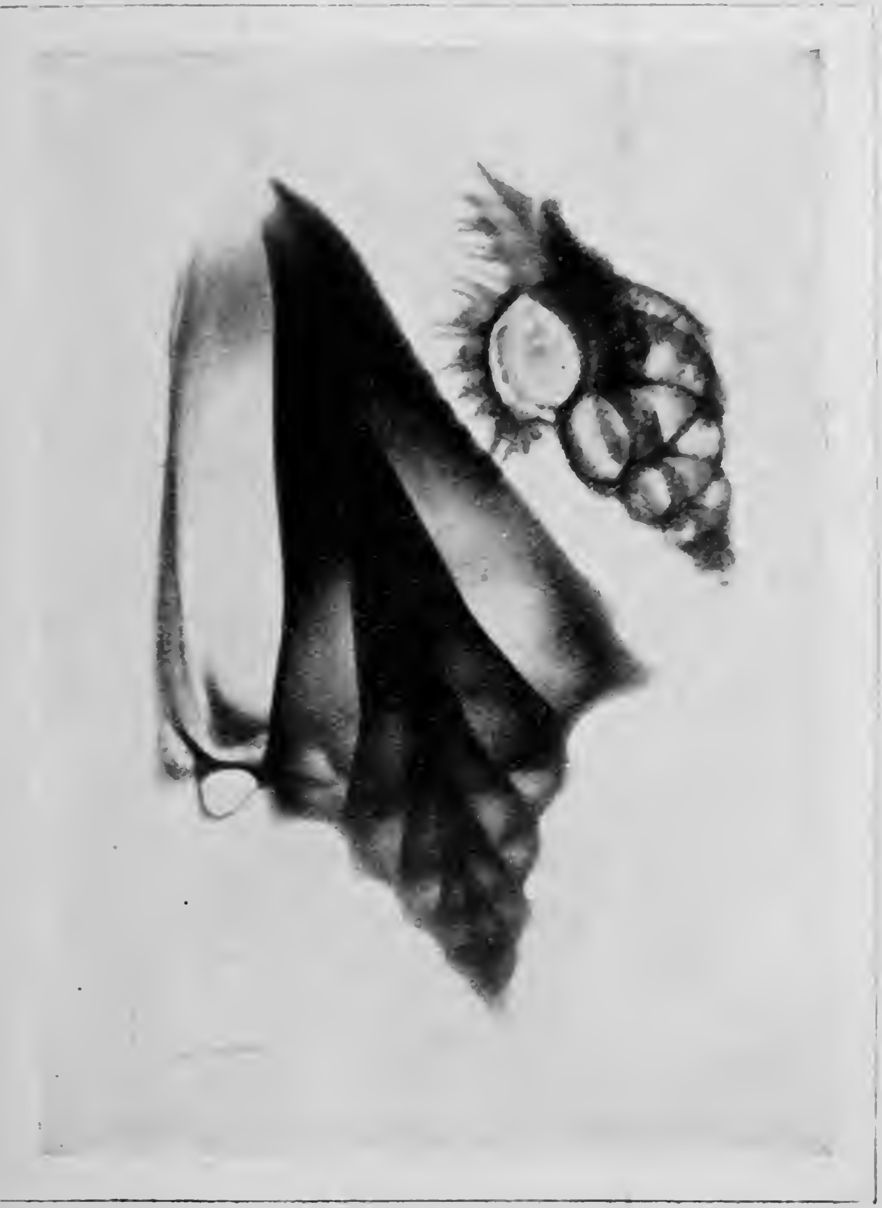


PLATE VII.

vention of a shutter moved synchronously with the flashes produced by the sources. H. Boas employed a special tube with two anti-cathodes, excited alternately by two similar spark coils and a specially adapted mercury interrupter. Few amateurs will find the means for experimenting with such appliances.

PRINTED IN GREAT BRITAIN BY NEILL AND CO., LTD., EDINBURGH.